NOVEL GLYCOCONJUGATES, GLYCOAMINO ACIDS, INTERMEDIATES THERETO, AND USES THEREOF

Priority Information

This application claims priority under § 119(e) of the United States Code to provisional application 60/150,088, filed August 20, 1999, entitled "Synthesis and Bioconjugation of the n-Pentenyl Glycoside of the Tumor-Associated Antigen Fucosyl GM1", the entire contents of which are hereby incorporated by reference.

Government Support

The present invention was supported by the National Institutes of Health Grant Numbers: AI16943 and CA28824. Therefore, the government has certain rights in the present invention.

Background of the Invention

The improvement of existing therapeutics and the development of novel therapeutics to treat and/or prolong survival of cancer patients has been the subject of continuing research in the scientific community. Although certain of these efforts have been directed to more "traditional" chemotherapeutics (e.g., Paclitaxel and other small molecule and/or natural product based therapies) that act by killing malignant cancer cells, it has also been a long-standing goal (Lanzavechis, *Science*, **260**, 937-944; Pardoll *et al.*, *Curr. Opin. Immunol.* **1993**, *5*, 719-725; Livingston *et al.*, *Curr. Opin. Immunol.* **1992**, *4*, 2; Dranoff *et al., Proc. Natl. Acad. Sci, USA* **1993**, *90*, 3539; M.H. Taoet *et al.*, *Nature*, **1993**, *362*, 755; T. Boon, *Int. J. Cancer* **1993**, *54*, 177) to develop an anti-cancer vaccine to induce an anticancer response. Although cancer vaccines have thus far been perceived as a mode of treatment subsequent to the detection of the disease (for example, by providing an enhanced immunological response), it would be most desirable to develop a selective synthetic vaccine that would be able to provide enhanced protection against tumor recurrence and metastasis when the tumor burden has been rendered minimal through surgery, radiation or other chemotherapeutic treatment.

In general, tumor immunotherapy is based on the theory that tumors possess specific antigens that can be recognized when presented to or processed by a properly

trained immune system. The goal for the development of an effective anticancer vaccine is to break the tolerance which the immune system has for these antigens expressed mainly or exclusively by the tumor, by presenting glycoconjugates as versions of immunostimulatory antigens, to induce an effective immune response. In an effort to achieve this goal, identified cancer carbohydrate antigens such as TF, Tn, sTN, KH-1, Le^y and Globo-H have been carefully characterized as being over-expressed at the surface of malignant cells in a variety of cancers (breast, colon, prostate, ovarian, liver, small cell lung and adenocarcinomas). In addition, they have been immunocharacterized by monoclonal antibodies and therefore have relevant serological markers available for immunological studies. Such studies have suggested that patients immunized in an adjuvant setting with carbohydrate-based vaccines produce antibodies reactive with human cancer cells, and that the production of such antibodies prohibits tumor recurrence and correlates with a more favorable diagnosis (see, Livingston et al., *J. Cancer Res.* **1989**, *49*, 7045; Ragupathi, G. *Cancer Immunol. Immunother.* **1996**, *43*, 152). Additionally, the isolation and careful structural identification of specific carbohydrate antigens overexpressed in cancer cells has provided a framework for an attack using carbohydrate-based tumor immunotherapy (For reviews see (a) Hakomori, S.; Zhang, Y. *Chem. Biol.* **1997**, *4*, 97; (b) Toyokuni, T.; Singhal, A. K. *Chem. Soc. Rev.* **1995**, *24*, 23 and references therein).

A major drawback in using carbohydrate epitopes, however, is that they are generally not readily available by isolation from natural sources. For example, the immense difficulties associated with their purification from natural sources render them virtually nonavailable as homogeneous starting materials for a clinical program. Thus, the incorporation of these naturally occurring epitopes into carrier proteins or any favorable molecular context via conjugation for eliciting a therapeutically useful immunological response is inefficient at best, and often virtually impossible. Therefore, to effectively study these vaccines as therapeutic agents, sufficient material can only be obtained by total chemical synthesis.

In an effort to remedy this problem, one of the continuing research efforts is the development of anti-cancer vaccines that incorporate fully synthetic carbohydrate moieties (For a review, see Danishefsky, S.J.; Allen, J.R. *Angew Chem. Int. Ed.* **2000**, *39*,

836-863). One strategy for the development of synthetic anti-cancer vaccines involves the total synthesis of the carbohydrate epitope and its subsequent covalent bioconjugation to carrier protein. The vaccine constructs are then subjected to appropriate mouse immunization studies, with the ultimate goal of advancing to human clinical trials. This strategy has resulted in several fully synthetic tumor associated carbohydrate-based vaccines which are at various stages of advanced pre-clinical and clinical processing. In fact, a Globo-H vaccine is undergoing clinical evaluation for the treatment of prostate and breast carcinomas at the phase II level (see, for example, Ragupathi *et al.*, *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 125) while a Lewis^y antigen-based vaccine, already tested in ovarian cancer, is awaiting more extensive follow-up evaluation (see, Kudryashov *et al. Cancer Immunol. Immunother.* **1998**, *45*, 281).

Although several synthetic constructs have been developed in recent years, as described above, and in other references described herein, there remains a need for the further investigation to develop novel constructs capable of eliciting a more sustained or effective (and preferably selective) immune response. Clearly, in an effort to achieve this goal, it would be useful to develop improved and/or novel synthetic methods to access heretofore synthetically unavailable antigenic components (e.g., more complex antigenic components such as fucosyl GM1, clustered epitopes and similar structures), or to access non-natural structures derived from naturally occurring structures for further immunologic and therapeutic studies.

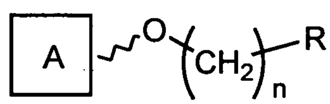
Summary of the Invention

In recognition of the need to further develop novel constructs and improved synthetic methods, the present invention, in one aspect, provides novel n-alkenyl glycosides and glycoconjugates, n-alkyl glycoamino acids, and methods for the synthesis thereof. In another aspect, the present invention provides novel clustered glycopeptides and methods for the synthesis thereof. In still another aspect, the present invention provides methods for the treatment of cancer, preferably for the prevention of recurrence of cancer, and methods for inducing antibodies in a subject comprising administering to a subject in need, an effective amount of any of the inventive glycoconjugates as disclosed herein.

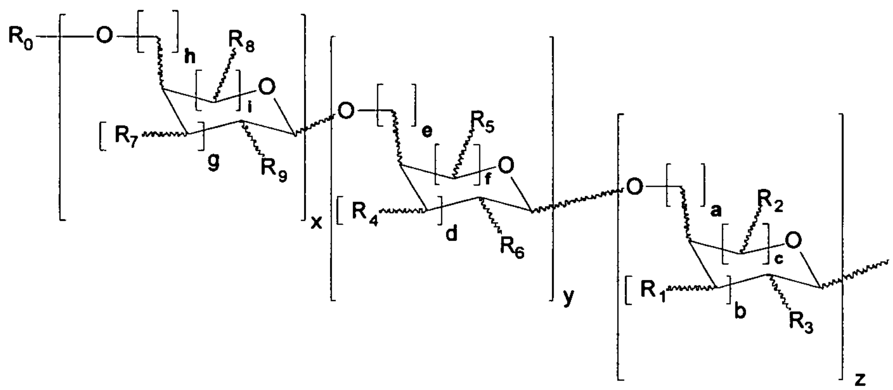
The general synthetic methodology disclosed herein involves the realization that the incorporation of an n-alkenyl glycoside protecting group at the reducing end of a carbohydrate acceptor allows for increased coupling efficiencies and accessibility to complex carbohydrates. Thus, the present invention also provides the recognition that for certain protected carbohydrates, the n-alkenyl moieties can serve as useful precursors that can be utilized ultimately for the synthesis of complex glycopeptides.

Thus, in one aspect, the present invention provides novel synthetic methodologies for the synthesis of complex carbohydrates comprising (1) providing a carbohydrate acceptor having a reducing end alkenyl group; (2) providing a suitable donor compound and (3) coupling said donor and acceptor under conditions to generate an alkenyl glycoside. Using this method, complex antigenic alkenyl glycosides are provided, as described above, many of which never before have been provided, which can then be conjugated or further reacted, as described herein, to generate glycoconjugates and glycopeptide structures.

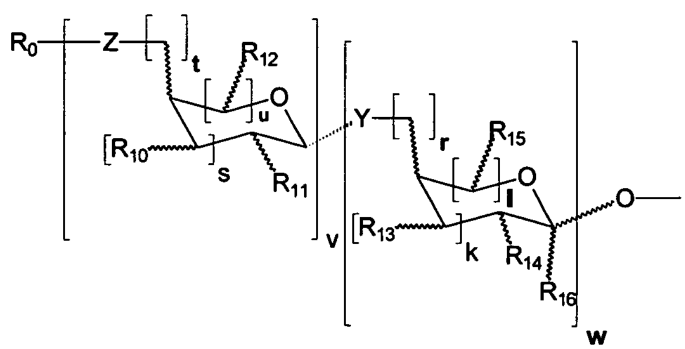
In general, the present invention provides novel compounds and/or conjugates having the general structure:



wherein R is hydrogen; substituted or unsubstituted alkyl; alkenyl; aryl; $-CH_2CH(CO_2R')(NHR'')$, wherein R' or R'' are each indpendently hydrogen, protecting group, substituted or unsubstituted alkyl, a linker, aryl, peptide, protein or lipid; or NHR''', wherein R''' is a protein, peptide, or lipid linked to N directly or through a crosslinker; wherein n is 0-8; wherein A is a carbohydrate domain having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



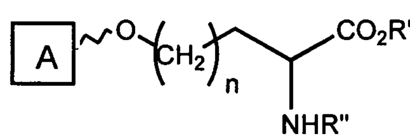
wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is

hydrogen, COOH, COOR^{ii}, CONHR^{ii}, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, COOR^{iv}, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group;

with the proviso that if A is KH-1, N3, globo-H, glycophorin, Tn, TF, STN, (2,3)ST, 2,6-STn or Le^{y}, and A is α-O-linked, then n is at least 1.

In certain preferred embodiments of the present invention, R is allyl, n is 2 and thus the inventive compound is a n-pentenyl moiety. In certain other embodiments of the present invention, R is NHR''', and the protein R''' is KLH or Bovine Serine Albumin. In still other embodiments of the present invention, R is NHR''', and the lipid R''' is PamCys. It will be appreciated that the protein or lipid can be linked to N directly or through a crosslinker, and thus R''' incorporates proteins, peptides, and lipids, as well as (crosslinker-protein), (crosslinker-peptide) and (crosslinker-lipid) moieties. In certain preferred embodiments, the crosslinker is MMCCH (4-(maleimidomethyl) cyclohexane-1-carboxyl hydrazide).

In other embodiments, the inventive compound is a glycoamino acid and thus R is $CH_2CH(CO_2R')(NHR'')$, which compound has the structure



In certain preferred embodiments, the glycoamino acids of the present invention are derived from n-pentenyl glycosides and thus n is 3. In certain other preferred embodiments, R' and R" are each a protecting group independently selected from the group consisting of *t*-butyl, TSE (2-(trimethylsilyl ethyl), Ac (acetyl), Boc (*t*-butoxycarbonyl), and Fmoc (9-fluoroenyl methoxy carbonyl).

For each of the compounds described above, in certain preferred embodiments the carbohydrate determinant is selected from the group consisting of Globo-H, fucosyl GM1, KH-1, glycophorin, N3, Tn, TF, STN, (2,3)ST, 2,6-STn, and Le^{y}. In other

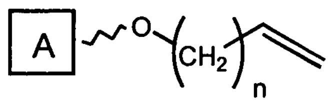
preferred embodiments, the carbohydrate determinant of the compound contains a Globo-H determinant or fucosyl GM1 determinant, as all or part of the carbohydrate determinant A.

Additionally, the present invention provides methods for the synthesis of novel n-alkyl glycoamino acids, as described in more detail below for Globo-H and fucosyl GM1 and their subsequent use to generate novel glycopeptides and synthetic constructs thereof.

In general, the inventive method for the production of these novel glycoamino acids comprises: 1) providing an alkenyl glycosidic moiety, as described herein; 2) subjecting said alkenyl glycosidic moiety to oxidative conditions to generate an aldehyde; 3) subjecting said aldehyde to olefination conditions to generate an enamide ester; 4) subjecting said resulting enamide ester to conditions sufficient to hydrogenate said enamide ester to generate a protected glycoamino acid and 5) deprotecting said protected glycoamino acid under suitable conditions to generate a desired glycoamino acid.

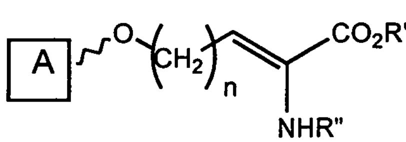
In particular, a method for the synthesis of a glycoamino acid, the structure of which is set forth herein, is provided, which comprises the steps of:

(a) providing an alkenyl glycoside having the structure:

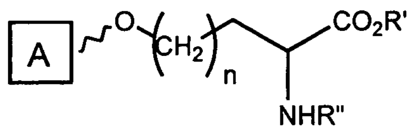


(b) reacting said alkenyl glycoside under suitable conditions to generate an enamide

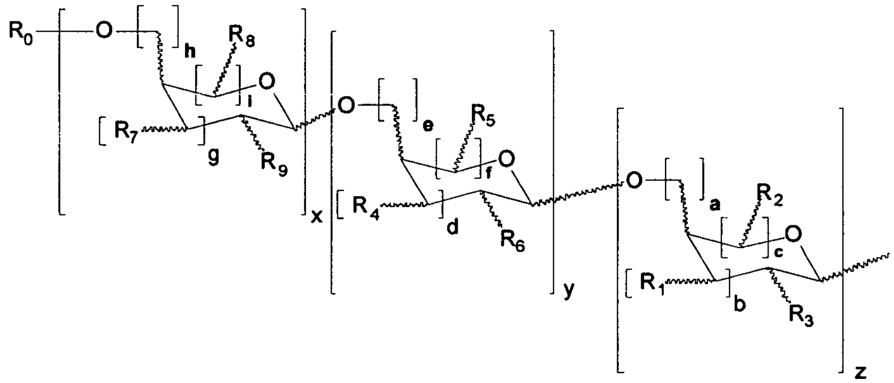
ester having the structure:



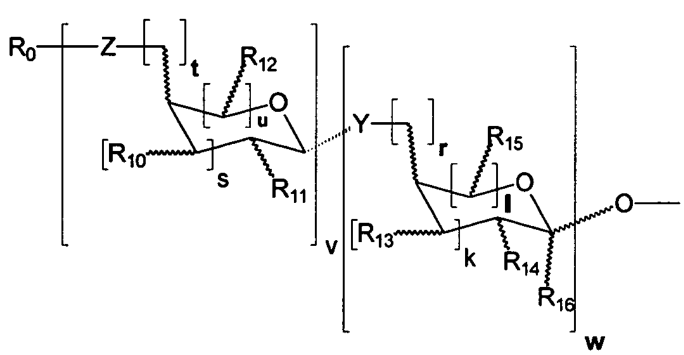
(b) reacting said enamide ester under suitable conditions to generate a glycoamino acid having the structure:



wherein, for each of the structures above, n is 0-8, wherein A is a carbohydrate domain having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4 , R_5, R_6 , R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



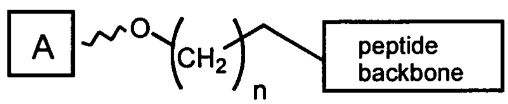
wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$, $CONHR^{ii}$, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group;

and wherein for the glycoamino acid structure R' and R" are each independently hydrogen, protecting group, substituted or unsubstituted alkyl, linker, aryl, peptide, protein or lipid; or NHR"', wherein R"' is a protein, peptide, or lipid, linked to N directly or through a crosslinker. In preferred embodiments, R' and R" are each independently hydrogen or a protecting group. In particularly preferred embodiments R" is a nitrogen protecting group, including, but not limited to, acetyl, Fmoc, or Boc, and R' is an acid protecting group such as *t*-butyl or TSE. In certain preferred embodiments, the carbohydrate determinant is selected from the group consisting of Globo-H, fucosyl GM1, KH-1, glycophorin, STN, (2,3)ST, Le^y, N3, Tn, 2,6-STn, and TF. In certain other preferred embodiments, the carbohydrate determinant of the compound contains a Globo-H determinant or a fucosyl GM1 determinant, as described herein, as all or part of the carbohydrate determinant A.

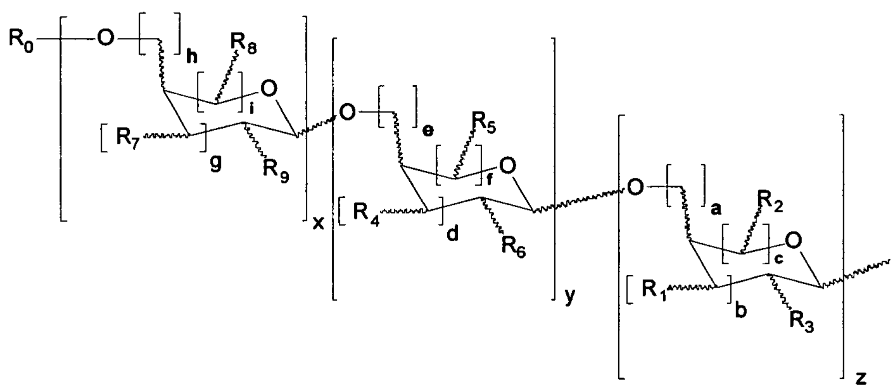
In general, in preferred embodiments, the step of reacting an n-alkenyl glycoside under suitable conditions to generate an enamide ester comprises reacting an n-alkenyl glycoside first under oxidative conditions and second under olefination conditions in the presence of base (e.g., tetramethylguanidine) and phosphonate to generate an enamide ester.

Additionally, the step of reacting said enamide ester under suitable conditions to generate a glycoamino acid comprises reacting said enamide ester under hydrogenation conditions.

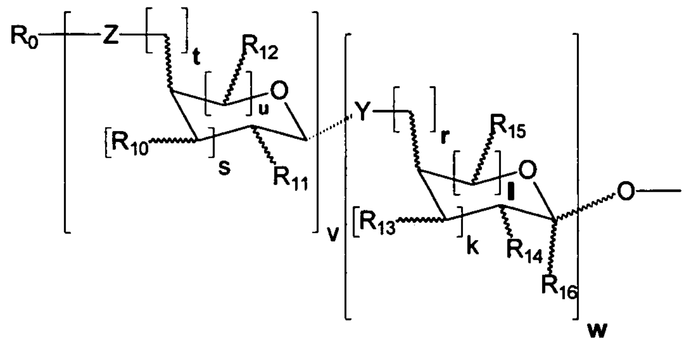
In another aspect of the present invention, multi-antigenic glycopeptides are provided comprising a peptidic backbone made up of at least three glycoamino acids, wherein one or more of said amino acids are substituted with an n-alkyl glycosidic moiety having the structure:



wherein each occurrence of A is independently a carbohydrate determinant having the structure:



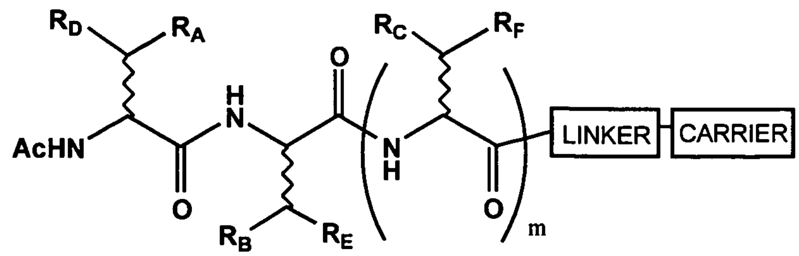
wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4 , R_5, R_6 , R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



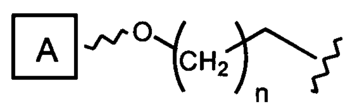
wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$, $CONHR^{ii}$, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group;

wherein each occurrence of n is independently 0-8, whereby, if for each occurrence of n, n = 0, at least one occurrence of A has a different structure from other occurrences of A; and wherein the n-alkyl glycosidic moiety is either α- or β-linked to an amino acid residue of the backbone. It will be appreciated that these inventive clustered glycopeptides are not limited to n-alkyl where n is greater than or equal to 1; rather multi-antigenic clustered glycopeptides can be linked via the traditional direct linkage (n=0) or via n-alkyl (such as pentyl) or any combination thereof. In other embodiments, each occurrence of A may be the same, however, n-alkenyl (n greater than 1) linkages are then utilized. In preferred embodiments, each occurrence of A is independently selected from the group consisting of Globo-H, fucosyl GM1, KH-1, glycophorin, STN, (2,3)ST, Le^y, N3, Tn, 2,6-STn, and TF.

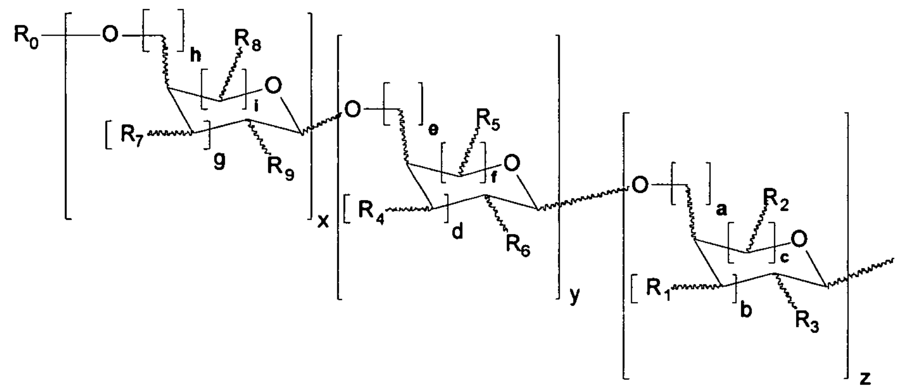
In certain embodiments, trimeric antigenic clusters are desirable and thus the present invention also provides constructs attached to a linker via a carrier protein having the following structure:



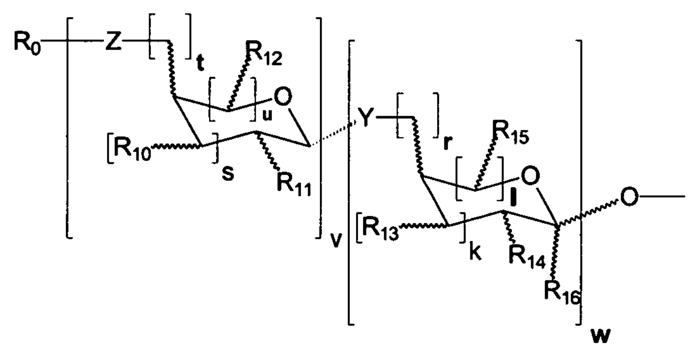
wherein the linker is either a free carboxylic acid, (carboxamido)alkyl carboxamide, MBS, primary carboxamide, mono- or dialkyl carboxamide, mono- or diarylcarboxamide, linear or branched chain (carboxy)alkyl carboxamide, linear or branched chain (alkoxycarbonyl)alkyl-carboxamide, linear or branched chain (carboxy)arylalkylcarboxamide, linear or branched chain (alkoxycarbonyl)alkylcarboxamide, an oligoester fragment comprising from 2 to about 20 hydroxy acyl residues, a peptidic fragment comprising from 2 to about 20 amino acyl residues, or a linear or branched chain alkyl or aryl carboxylic ester; wherein the carrier is a protein or lipid; wherein m is 1, 2 or 3; wherein R_A, R_B and R_C are each independently H or methyl; and wherein R_D, R_E and R_F are each independently an alkyl glycosidic moiety having the structure:



wherein each occurrence of A is independently selected from a carbohydrate domain having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein the carbohydrate domain is linked to the respective amino acyl or hydroxy acyl residue by substitution of a side group substituent selected from the group consisting of OH, COOH and NH_2; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4 , R_5, R_6 , R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a

substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$, $CONHR^{ii}$, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein each occurrence of n is independently 0-8, whereby, if for each occurrence of n, n = 0, at least one occurrence of A has a different structure from other occurrences of A; and wherein the n-alkyl glycosidic moiety is either α- or β-linked to an amino acid.

In preferred embodiments, each occurrence of A is selected from the group consisting of Globo-H, fucosyl GM1, KH-1, glycophorin, STN, (2,3)ST, Le^y, N3, Tn, 2,6 STn and TF. In but one preferred example, the present invention provides a novel trimeric antigenic glycopeptide incorporating globo-H, Le^y and Tn, to generate a novel trimeric antigenic compound.

As detailed herein, in another aspect of the present invention, any of the inventive compounds may be conjugated to generate a glycoconjugate, and may be administered alone or with an immunological adjuvant for the treatment of the recurrence of cancer or may be administered alone or with an immunological adjuvant to induce antibodies in a subject.

Definitions

Certain compounds of the present invention, and definitions of specific functional groups are also described in more detail below. For purposes of this invention, the chemical elements are identified in accordance with the Periodic Table of the Elements, CAS version, Handbook of Chemistry and Physics, 75th Ed., inside cover, and specific functional groups are defined as described therein. Additionally, general principles of organic chemistry, as well as specific functional moieties and reactivity, are described in "Organic Chemistry", Thomas Sorrell, University Science Books, Sausalito: 1999, the entire contents of which are incorporated herein by reference.

It will be appreciated that the compounds, as described herein, may be substituted with any number of substituents or functional moieties. In general, the term "substituted"

whether preceded by the term “optionally” or not, and substituents contained in formulas of this invention, refer to the replacement of hydrogen radicals in a given structure with the radical of a specified substituent. When more than one position in any given structure may be substituted with more than one substituent selected from a specified group, the substituent may be either the same or different at every position. As used herein, the term "substituted" is contemplated to include all permissible substituents of organic compounds. In a broad aspect, the permissible substituents include acyclic and cyclic, branched and unbranched, carbocyclic and heterocyclic, aromatic and nonaromatic substituents of organic compounds. For purposes of this invention, heteroatoms such as nitrogen may have hydrogen substituents and/or any permissible substituents of organic compounds described herein which satisfy the valencies of the heteroatoms. Furthermore, this invention is not intended to be limited in any manner by the permissible substituents of organic compounds. Combinations of substituents and variables envisioned by this invention are preferably those that result in the formation of stable compounds useful in the treatment of cancer, or in the inducement of antibodies, as described herein. The term “stable”, as used herein, preferably refers to compounds which possess stability sufficient to allow manufacture and which maintain the integrity of the compound for a sufficient period of time to be useful for the purposes detailed herein.

The term “aliphatic”, as used herein, includes both saturated and unsaturated, straight chain (i.e., unbranched), branched, cyclic, or polycyclic aliphatic hydrocarbons, which are optionally substituted with one or more functional groups. As will be appreciated by one of ordinary skill in the art, “aliphatic” is intended herein to include, but is not limited to, alkyl, alkenyl, alkynyl, cycloalkyl, cycloalkenyl, and cycloalkynyl moieties. Thus, as used herein, the term “alkyl” includes both straight, branched and cyclic alkyl groups. An analogous convention applies to other generic terms such as “alkenyl”, “alkynyl” and the like. Furthermore, as used herein, the terms “alkyl”, “alkenyl”, “alkynyl” and the like encompass both substituted and unsubstituted groups.

The term "alkylamino" refers to a group having the structure -NHR' wherein R' is alkyl, as defined herein. Examples of alkylamino include, but are not limited to, methylamino, ethylamino, iso-propylamino and the like.

Some examples of substituents of the above-described aliphatic (and other) moieties of compounds of the invention include, but are not limited to: F, Cl, Br, I, OH, NO_2, CN, C(O)-C_1-C_6-alkyl, C(O)-aryl, C(O)-heteroaryl, CO_2-alkyl, CO_2-aryl, CO_2-heteroaryl, $CONH_2$, CONH-C_1-C_6-alkyl, CONH-aryl, CONH-heteroaryl, OC(O)-C_1-C_6-alkyl, OC(O)-aryl, OC(O)-heteroaryl, OCO_2-alkyl, OCO_2-aryl, OCO_2-heteroaryl, $OCONH_2$, OCONH-C_1-C_6-alkyl, OCONH-aryl, OCONH-heteroaryl, NHC(O)-C_1-C_6-alkyl, NHC(O)-aryl, NHC(O)-heteroaryl, $NHCO_2$-alkyl, $NHCO_2$-aryl, NHCONH-heteroaryl, SO_2-C_1-C_6-alkyl, SO_2-aryl, C_3-C_6-cycloalkyl, CF_3, CH_2CF_3, $CHCl_2$, CH_2OH, CH_2CH_2OH, CH_2NH_2, $CH_2SO_2CH_3$, aryl, heteroaryl, benzyl, benzyloxy, aryloxy, heteroaryloxy, C_1-C_6-alkoxy, methoxymethoxy, methoxyethoxy, amino, benzylamino, arylamino, heteroarylamino, C_1-C_3-alkyl-amino, thio, aryl-thio, heteroarylthio, benzyl-thio, C_1-C_6-alkyl-thio, or methylthiomethyl. Additional examples of generally applicable substituents are illustrated by the specific embodiments shown in the Examples which are described herein.

In general, the terms “aryl” and “heteroaryl”, as used herein, refer to stable mono- or polycyclic, heterocyclic, polycyclic, and polyheterocyclic unsaturated moieties having preferably 3-14 carbon atoms, each of which may be substituted or unsubstituted. Substituents include, but are not limited to, any of the previously mentioned substitutents, i.e., the substituents recited for aliphatic moieties, or for other moieties as disclosed herein, resulting in the formation of a stable compound. In certain embodiments of the present invention, "aryl" refers to a mono- or bicyclic carbocyclic ring system having one or two aromatic rings including, but not limited to, phenyl, naphthyl, tetrahydronaphthyl, indanyl, indenyl and the like. In certain embodiments of the present invention, the term "heteroaryl", as used herein, refers to a cyclic aromatic radical having from five to ten ring atoms of which one ring atom is selected from S, O and N; zero, one or two ring atoms are additional heteroatoms independently selected from S, O and N; and the remaining ring atoms are carbon, the radical being joined to the rest of the molecule via any of the ring atoms, such as, for example, pyridyl, pyrazinyl, pyrimidinyl, pyrrolyl, pyrazolyl, imidazolyl, thiazolyl, oxazolyl, isooxazolyl, thiadiazolyl,oxadiazolyl, thiophenyl, furanyl, quinolinyl, isoquinolinyl, and the like.

It will be appreciated that aryl and heteroaryl groups (including bicyclic aryl groups) can be unsubstituted or substituted, wherein substitution includes replacement of one, two or three of the hydrogen atoms thereon independently with any one or more of the following moieties including, but not limited to: F, Cl, Br, I, OH, NO_2, CN, C(O)-C_1-C_6-alkyl, C(O)-aryl, C(O)-heteroaryl, CO_2-alkyl, CO_2-aryl, CO_2-heteroaryl, $CONH_2$, CONH-C_1-C_6-alkyl, CONH-aryl, CONH-heteroaryl, OC(O)-C_1-C_6-alkyl, OC(O)-aryl, OC(O)-heteroaryl, OCO_2-alkyl, OCO_2-aryl, OCO_2-heteroaryl, $OCONH_2$, OCONH-C_1-C_6-alkyl, OCONH-aryl, OCONH-heteroaryl, NHC(O)-C_1-C_6-alkyl, NHC(O)-aryl, NHC(O)-heteroaryl, $NHCO_2$-alkyl, $NHCO_2$-aryl, NHCONH-heteroaryl, SO_2-C_1-C_6-alkyl, SO_2-aryl, C_3-C_6-cycloalkyl, CF_3, CH_2CF_3, $CHCl_2$, CH_2OH, CH_2CH_2OH, CH_2NH_2, $CH_2SO_2CH_3$, aryl, heteroaryl, benzyl, benzyloxy, aryloxy, heteroaryloxy, C_1-C_6-alkoxy, methoxymethoxy, methoxyethoxy, amino, benzylamino, arylamino, heteroarylamino, C_1-C_3-alkyl-amino, thio, aryl-thio, heteroarylthio, benzyl-thio, C_1-C_6-alkyl-thio, or methylthiomethyl. Additional examples of generally applicable substitutents are illustrated by the specific embodiments shown in the Examples which are described herein.

The term "cycloalkyl", as used herein, refers specifically to groups having three to seven, preferably three to ten carbon atoms. Suitable cycloalkyls include, but are not limited to cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl and the like, which, as in the case of other aliphatic, heteroaliphatic or hetercyclic moieties, may optionally be substituted. F, Cl, Br, I, OH, NO_2, CN, C(O)-C_1-C_6-alkyl, C(O)-aryl, C(O)-heteroaryl, CO_2-alkyl, CO_2-aryl, CO_2-heteroaryl, $CONH_2$, CONH-C_1-C_6-alkyl, CONH-aryl, CONH-heteroaryl, OC(O)-C_1-C_6-alkyl, OC(O)-aryl, OC(O)-heteroaryl, OCO_2-alkyl, OCO_2-aryl, OCO_2-heteroaryl, $OCONH_2$, OCONH-C_1-C_6-alkyl, OCONH-aryl, OCONH-heteroaryl, NHC(O)-C_1-C_6-alkyl, NHC(O)-aryl, NHC(O)-heteroaryl, $NHCO_2$-alkyl, $NHCO_2$-aryl, NHCONH-heteroaryl, SO_2-C_1-C_6-alkyl, SO_2-aryl, C_3-C_6-cycloalkyl, CF_3, CH_2CF_3, $CHCl_2$, CH_2OH, CH_2CH_2OH, CH_2NH_2, $CH_2SO_2CH_3$, aryl, heteroaryl, benzyl, benzyloxy, aryloxy, heteroaryloxy, C_1-C_6-alkoxy, methoxymethoxy, methoxyethoxy, amino, benzylamino, arylamino, heteroarylamino, C_1-C_3-alkyl-amino, thio, aryl-thio, heteroarylthio, benzyl-thio, C_1-C_6-alkyl-thio, or methylthiomethyl. Additional examples

of generally applicable substitutents are illustrated by the specific embodiments shown in the Examples which are described herein.

The terms "halo" and "halogen" as used herein refer to an atom selected from fluorine, chlorine, bromine and iodine.

It will be appreciated that additional examples of generally applicable substitutents are illustrated by the specific embodiments shown in the Examples which are described herein, but are not limited to these Examples.

Description of the Drawing

Figure 1 depicts Fucosyl GM1, derivatives and constructs thereof.

Figure 2 depicts synthesis of the ABC trisaccharide **4** and depicts the thioethyl donor **5**.

Figure 3 depicts the synthesis of hexasaccharide **6a** and the synthesis of Fucosyl GM_1 pentenyl glycoside **1b**. Reagents: (a) MeOTf, CH_2Cl_2:Et_2O (2:1), 0°C, 23%; (b) (i) DMDO, CH_2Cl_2; (ii) PnOH, $ZnCl_2$, -78°C, 65%; (c) TBAF, AcOH, THF; (d) NaOMe, MeOH; (e) NaOH, THF; (f) Na/NH_3, THF –78°C, then MeOH; (g) Ac_2O, pyridine, DMAP, CH_2Cl_2, 46% 5 steps.

Figure 4 depicts the synthesis of trisaccharide acceptor **15**. Reagents: (a) Ag_2CO_3, cat. I_2, PnOH, CH_2Cl_2, 75%; (b) NaOMe, MeOH; (c) Acetone, cat. PPTS, 44% 2 steps; (d) BnBr, NaH, DMF; 84%; (e) 80% AcOH: H_2O, 90%; (f) **3**, TMSOTf, EtCN, molecular sieves, -40°C, 77%.

Figure 5 depicts the synthesis of Fucosyl GM_1 Pentenyl Glycoside. Reagents: (a) MeOTf, CH_2Cl_2:Et_2O, 0°C, 70%; (b) TBAF, AcOH, THF; (c) NaOMe, MeOH; (d) NaOH, THF; (e) Na/NH_3, THF, -78°C, then MeOH; (f) Ac_2O, pyridine, DMAP, CH_2Cl_2, 45% 5 steps, (g) steps c-d, 96%.

Figure 6 depicts the synthesis of Fucosyl GM_1 KLH conjugate **1c**.

Figure 7 depicts Globo-H, derivatives and constructs thereof.

Figure 8 depicts a synthetic scheme for a second generation synthesis of globo-H and constructs thereof.

Figure 9 depicts a retrosynthetic analysis of Globo-H and conjugates thereof.

Figure 10 depicts the synthesis of glycoside **25** and thioethyl donor **28**. Reagents: (a) HBr, Ac_2O, AcOH, 96%; (b) PentOH, Ag_2CO_3, CH_2Cl_2, 4Å molecular sieves, 75%; c) NaOMe, MeOH; then Dowex-H^+; (d) BnBr, Bu_2SnO, Bu_4NI, C_6H_6, 54% two steps; e) $PhCH(OMe)_2$, CSA, CH_3CN, 72%; (f) BnBr, NaH, DMF, Et_4NI, 97%; (g) $NaCNBH_3$, HCl, Et_2O, THF, 79%; (h) DMDO, CH_2Cl_2; (i) HF/pyridine, 85% two steps; (j) BnBr, NaH, DMF, 95%; (k) $Cp_2Zr(OTf)_2$, toluene/THF 5:1, 80% (α), α:β 10:1; (l) DDQ, CH_3CN, H2O, 84%.

Figure 11 depicts the synthesis of Globo-H Pentenyl Glycoside (**16c**).

Figure 12 depicts the conjugation of Globo-H to carrier protein KLH.

Figure 13 depicts immunoconjugation of tumor antigens Globo-H and Fucosyl GM_1 and the developed glycoamino acid sequence.

Figure 14 depicts the synthesis of peracetylated lactose amino acid derivatives.

Figure 15 depicts the synthesis of a peptide containing the Tn antigen, Lewis^y antigen, and the MBr1 antigen. Reagents: (a) TBAF, THF; (b) $AcSCH_2C(O)(CH_2)_3NH_2$, BOP reagent, *i*Pr_2NEt, 54%, 2 steps; (c) TFA, CH_2Cl_2; (d) BOP reagent, *i*Pr_2NEt, 86%, 2 steps; (e) **52**, BOP reagent, *i*Pr_2NEt, 64%, 2 steps; (f) Ac_2O, Et_3N, cat. DMAP, 95%, 2 steps.

Figure 16 depicts the preparation of fully deprotected glycopeptide **54**.

Figure 17 depicts the synthesis of α-Tn pentenyl glycoside **40**.

Detailed Description of the Invention

As discussed above, the desire to develop improved methods for the preparation of fully synthetic vaccines has led to increased research efforts directed toward the synthesis of naturally occurring complex carbohydrate antigens, as well as novel complex structures (e.g., glycopeptides) incorporating these antigenic structures. As is often the case during the course of any such large synthetic undertaking, improved synthetic methods are often developed that can be applied universally. In particular, synthetic studies of naturally occurring antigenic structures has led to the development of novel methodologies enabling the development of heretofore unavailable synthetic carbohydrate-based vaccines. For a review, see Danishefsky, S.J.; Allen, J.R., *Angew. Chem. Int. Ed. Engl.* **2000**, *39*, 836-863, and references cited therein.

Significantly, the present invention provides improved methodologies for the synthesis of complex carbohydrates and related therapeutic compounds (e.g., glycoconjugates and/or glycopeptides). In particular, in the context of synthetic studies developed for the total syntheses of fucosyl GM1 and the n-pentenyl glycoside of Globo-H, generalized methodologies were developed for the improved synthesis of complex carbohydrate structures. This general synthetic method involves the realization that the incorporation of an n-alkenyl glycoside protecting group at the reducing end of a carbohydrate acceptor allows for increased coupling efficiencies and accessibility to complex carbohydrates. In yet another aspect, the present invention also provides the recognition that for certain protected carbohydrates, the n-alkenyl moieties can serve as useful precursors that can be utilized ultimately for the synthesis of complex glycopeptides.

Furthermore, the present invention also provides the recognition that the presence of the n-alkenyl moiety, whether or not in the context of an antigenic n-pentenyl glycoside or glycopeptide, is advantageous for the development of improved carbohydrate based therapeutics (e.g., fully synthetic vaccines) because more efficient syntheses of conjugation precursors can be prepared (and ultimately conjugated), and the n-alkenyl carbohydrate also serves as a precursor for the synthesis of novel n-alkyl glycoamino acids, as described herein. The ability to easily access these glycoamino acids allows for the ultimate synthesis of complex clustered glycopeptides. Significantly, the methodologies provided by the present invention, as described above and in more detail herein, allow the efficient preparation of complex glycopeptide structures having *more than one type* of carbohydrate determinant.

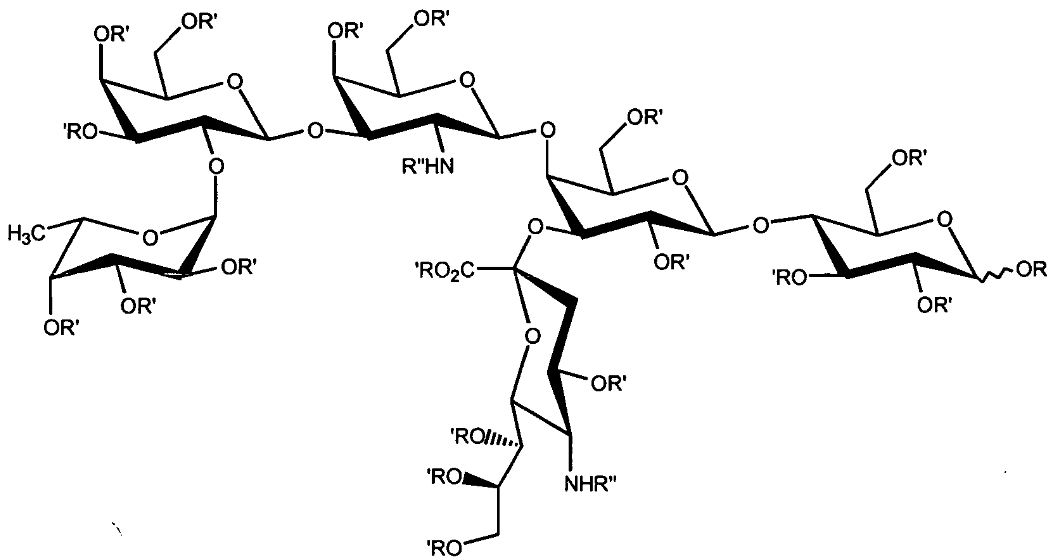
Specific examples, particularly with respect to the total synthesis of fucosyl GM1 and a novel synthetic scheme for the synthesis of the n-pentenyl glycoside of Globo-H are described in more detail below, along with certain general methodologies developed during the course of these syntheses. It will be appreciated by one of ordinary skill in the art that these examples are not intended to be limiting; rather all equivalents are intended to be incorporated into the scope of the present invention.

Inventive Compounds and Methods for the Synthesis Thereof

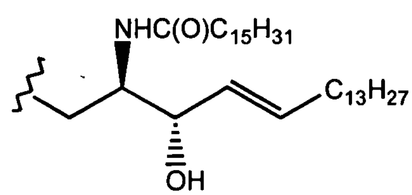
As mentioned, the total synthesis of complex antigenic structures has led to significant development in methodologies for complex carbohydrate synthesis. Of particular recent interest is the naturally occurring antigenic structure, fucosylated GM1 ganglioside as shown in Figure 1 (**1a**) which heretofore had not yet been synthesized. Nilsson *et al.* identified fucosyl GM1 as a specific marker associated with small lung cancer (SCLC) cells (Nilsson et al., *Glycoconjugate J.* **1984**, *1*, 43; Brezicka *et al.*, *Cancer Res.* **1989**, *49*, 1300). These workers isolated the glycosphingolipid fucosyl GM1 (**1a**) as the major ganglioside component contained in human SCLC tissue. Furthermore, monoclonal antibodies (F12) to the antigen serve to detect fucosyl GM1 in tissues and serum of SCLC patients (Nilsson *et al.*, *Cancer Res.* **1986**, *46*, 1403; Vangsted *et al.*, *Cancer Res.* **1991**, *51*, 2897). Immunohistochemistry studies have suggested that, due to its highly restricted distribution in normal tissues, fucosyl GM1 could be an excellent target for immune attack against SCLC. Remarkably, fucosyl GM1 has thus far not been found on any other human cancer cell lines, indicating that it is very SCLC tumor specific (Zhang *et al.*, *Int. J. Cancer* **1997**, *73*, 42).

The structural assignment of the carbohydrate moiety of the SCLC antigen was based on a combination of enzymatic and chemical degradations (Nilsson *et al.*, *Glycoconjugate J.* **1984**, *1*, 43). While there was no particular reason to question this assignment, the development of a carbohydrate based attack on SCLC could benefit from a definitive assignment of the linkage modes of the various monosaccharides, including the stereochemistry at each glycosidic attachment. Furthermore, no syntheses of this carbohydrate sector have appeared in the literature. In a preferred embodiment, a synthetic scheme would allow for presentation of the hexasaccharide epitope independent of the ceramide to the F12 mAb to ensure that all specificity is directed at the carbohydrate sector. In other preferred embodiments, the construct should be so functionalized as to anticipate the need for its conjugation to a carrier protein in anticipation of building an effective anti-tumor vaccine. As detailed herein, the ability to generate an n-alkenyl glycoside enables for the efficient synthesis of this epitope and allows for its effective modification and/or conjugation to build an effective anti-tumor vaccine.

Thus, in one aspect of the present invention, the synthesis of the complex fucosyl GM1 carbohydrate sector has been achieved and a compound having the structure as shown below is provided:



wherein each occurrence of R' is independently hydrogen or a protecting group; wherein each occurrence of R" is independently hydrogen or a nitrogen protecting group; wherein R is hydrogen, substituted or unsubstitued alkyl, alkenyl, -NHR'", wherein R'" is a protein, peptide or lipid linked to N directly or through a crosslinker, an amino acyl moiety, an amino acyl residue of a peptide, an amino acyl residue of a protein, which amino acyl moiety or residue, or –NHR'" is linked to O via a polymethylene chain having the structure $-(CH_2)_r$, where r is an integer between 1 and 9, or wherein R is substituted with a moiety having the structure:

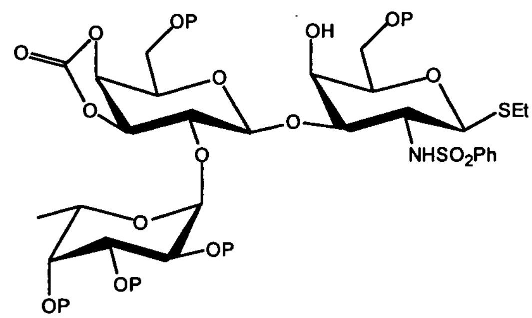


In certain preferred embodiments, each occurrence of R' is hydrogen. In certain other preferred embodiments of the present invention, R is n-alkenyl, including, but not

limited to allyl, propenyl, butenyl and pentenyl. In a particularly preferred embodiment, R is n-pentenyl. In certain other preferred embodiments, R is –NHR'", an amino acyl moiety, an amino acyl residue of a peptide, or an amino acyl residue of a protein, as described above, wherein r is preferably 4. In still other preferred embodiments, a compound as described above is provided, with the proviso that the compound is not the glycosphingolipid structure.

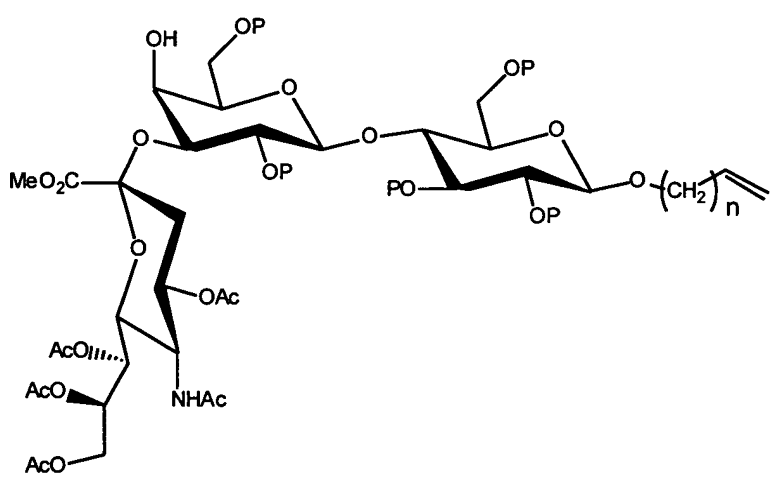
In another aspect of the present invention, a method for the synthesis of fucosyl GM1 glycoside is provided, said method comprising the steps of:

(a) providing a thioethyl donor having the structure:



wherein P is a protecting group;

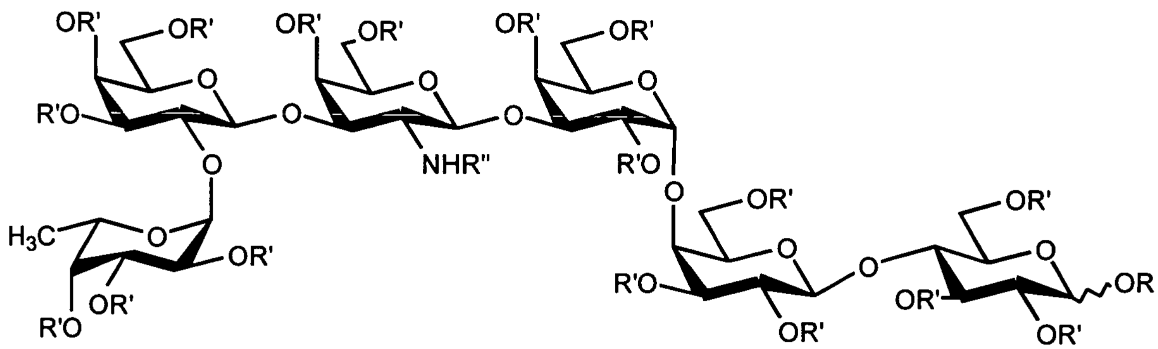
(b) providing a trisaccharide acceptor having the structure:



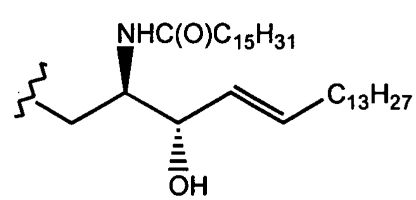
wherein n is 0-8, and wherein P is a protecting group; and

(c) reacting said thioethyl donor and said trisaccharide acceptor under conditions to generate a protected hexasaccharide and subsequently deprotecting the protected hexasaccharide under suitable conditions to generate n-alkenyl fucosyl GM1 glycoside.

In yet another aspect of the present invention, novel derivatives of Globo-H are provided and a novel general synthetic methodology for the synthesis thereof. The derivatives of Globo-H are depicted below:



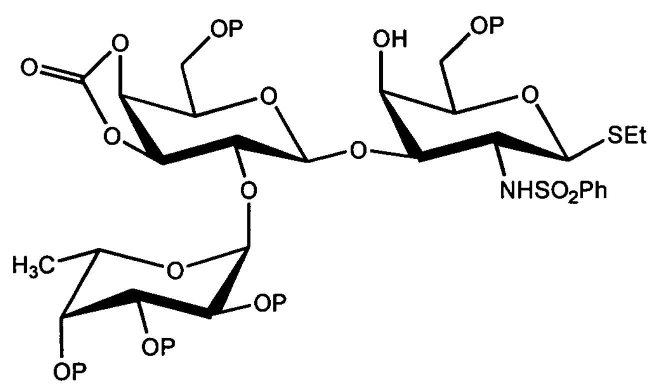
wherein each occurrence of R' is hydrogen or a protecting group, wherein R" is hydrogen or a nitrogen protecting group; wherein R is hydrogen, substituted or unsubstitued alkyl or alkenyl, wherein the alkenyl moiety has four or more carbons; -NHR'", wherein R'" is a protein, peptide or lipid linked to N directly or through a crosslinker; an amino acyl moiety; an amino acyl residue of a peptide; an amino acyl residue of a protein; which amino acyl moiety or residue or –NHR'" is linked to O via a polymethylene chain having the structure $-(CH_2)_r$, where, if said carbohydrate moiety is linked to O via an α-linkage, r is an integer between 2 and 9, or, alternatively, if said carbohydrate moiety is linked to O via a β-linkage, r is an integer between 1 and 9; or wherein R is substituted with a moiety having the structure:



In certain preferred embodiments, each occurrence of R' is hydrogen. In certain other preferred embodiments of the present invention, R is n-alkenyl, including, but not limited to allyl, propenyl, butenyl and pentenyl. In a particularly preferred embodiment, R is n-pentenyl. In certain other preferred embodiments, R is an amino acyl moiety, an amino acyl residue of a peptide, or an amino acyl residue of a protein, as described above, wherein r is preferably 4. In still other preferred embodiments, a compound as described above is provided, with the proviso that the compound is not the glycosphingolipid structure.

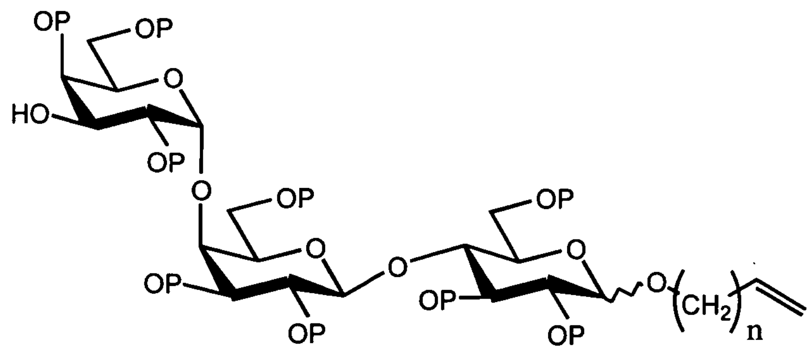
As described in more detail herein in Example 2, a similar methodology to that described for fucosyl GM1 is employed for the synthesis of Globo-H and derivatives thereof. Thus, in another aspect of the present invention, a method for the improved synthesis of Globo-H, and derivatives thereof, said method comprising the steps of:

(a) providing a thioethyl donor having the structure:



wherein P is a protecting group; and

(b) providing a trisaccharide acceptor having the structure:



wherein n is 0-8, and wherein P is a suitable protecting group; and

(c) reacting said thioethyl donor and said trisaccharide acceptor under conditions to generate a protected hexasaccharide and subsequently deprotecting the protected hexasaccharide under suitable conditions to generate n-alkenyl Globo-H.

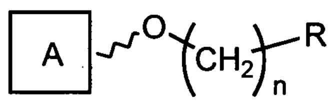
It will be appreciated that for each of the methods as detailed herein, the full arsenal of protecting groups known in the art of organic synthesis can be utilized, for example, as set forth in "Activating Agents and Protecting Groups: Handbook of Reagents for Organic Synthesis" Roush, W.R. and Pearson, A.J., Eds., John Wiley & Sons: 1999; and "Protective Groups in Organic Synthesis" Greene, T.W. and Wuts, P.G., John Wiley & Sons, New York: 1999, the entire contents of which are hereby incorporated by reference. In but a few examples, suitable protecting groups utilized herein include, but are not limited to, Bn (benzyl), TIPS (triisopropylsilyl), and Ac (acetate). In a preferred embodiment of the present invention, said thioethyl donor and said trisaccharide acceptor are reacted under MeOTf promotion, as described herein. It will be appreciated by one of ordinary skill in the art however, that a variety of conditions known in the art of organic synthesis can be utilized to effect coupling of these moieties.

It will also be appreciated that the novel n-alkenyl moieties provided herein can be subsequently modified to generate useful compounds (e.g., alkyl derivatives and glycoamino acids) or constructs thereof (e.g., glycopeptides and conjugated derivatives).

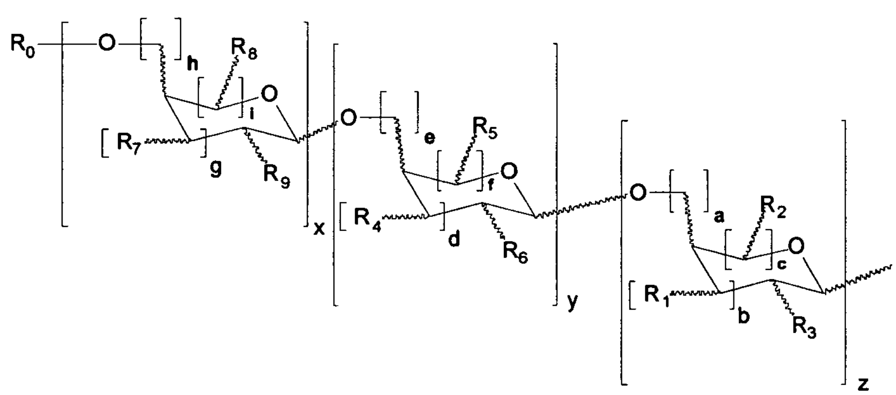
In addition to providing the first synthesis of fucosyl GM1 and improved synthetic methodologies for Globo-H, as described above, in a more general aspect, the present invention provides novel synthetic methodologies for the synthesis of complex carbohydrates comprising (1) providing a carbohydrate acceptor having a reducing end alkenyl group; (2) providing a suitable donor compound and (3) coupling said donor and

acceptor under conditions to generate an alkenyl glycoside. Using this method, complex antigenic alkenyl glycosides are provided, as described above, many of which never before have been provided, which can then be conjugated or further reacted, as described herein, to generate glycoconjugates and glycopeptide structures.

Thus, in general, the present invention provides novel compounds and/or conjugates having the general structure:

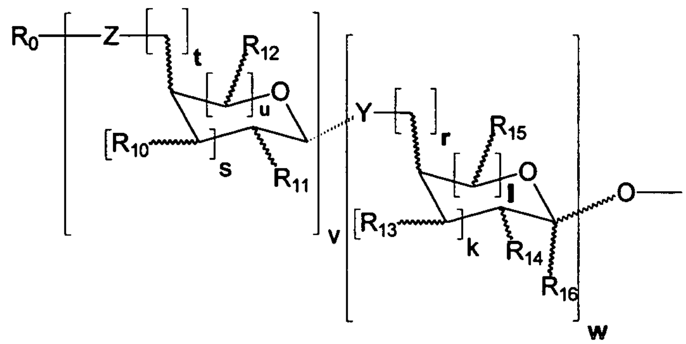


wherein R is hydrogen; substituted or unsubstituted alkyl; alkenyl; aryl; $-CH_2CH(CO_2R')(NHR'')$, wherein R' or R'' are each indpendently hydrogen, protecting group, substituted or unsubstituted alkyl, a linker, aryl, peptide, protein or lipid; or NHR''', wherein R''' is a protein, peptide, or lipid, linked to N directly or through a crosslinker; wherein n is 0-8; wherein A is a carbohydrate domain having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4 , R_5, R_6 , R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is

hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:

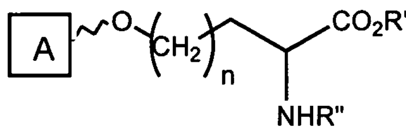


wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$, $CONHR^{ii}$, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group;

with the proviso that if A is KH-1, N3, globo-H, glycophorin, Tn, TF, STN, (2,3-ST), 2,6-STn or Le^y, and A is α-O-linked, then n is at least 1.

In certain preferred embodiments of the present invention, R is allyl, n is 2 and thus the inventive compound is a n-pentenyl moiety. In certain other embodiments of the present invention, R is NHR''', and the protein R''' is KLH or Bovine Serine Albumin. In still other embodiments of the present invention, R is NHR''', and the lipid R''' is PamCys. It will be appreciated that the protein or lipid can be linked to N directly or through a crosslinker and thus R''' incorporates proteins, peptides and lipids, as well as (crosslinker-protein), (crosslinker-peptide) and (crosslinker-lipid) moieties. In certain preferred embodiments, the crosslinker is MMCCH (4-(maleimidomethyl) cyclohexane-1-carboxyl hydrazide).

In still other embodiments, the inventive compound is a glycoamino acid and thus R is $CH_2CH(CO_2R')(NHR'')$, which compound has the structure:



In certain preferred embodiments, the glycoamino acids of the present invention are derived from n-pentenyl glycosides and thus n is 3. In certain other preferred embodiments, R' and R" are a protecting group, each independently selected from the group consisting of t-butyl, TSE, Boc, Fmoc and acetyl.

For each of the compounds described above, in certain preferred embodiments the carbohydrate determinant is selected from the group consisting of Globo-H, fucosyl GM1, KH-1, N3, glycophorin, Tn, TF, STN, (2,3)ST, 2,6-STn, and Le^y. In other preferred embodiments, the carbohydrate determinant of the compound contains a Globo-H determinant or fucosyl GM1 determinant as all of part of the carbohydrate determinant A.

As described above, specifically in the context of the second generation synthesis of the MBr1 antigen (GloboH) and the total synthesis of the fucosylated ganglioside of GM1 (fucosyl GM1), incorporating the reducing end n-alkenyl moiety (specifically n-pentenyl) offers certain benefits. First, the anomeric n-pentenyl glycoside linkage serves as an effective linker for immunoconjugation to carrier protein KLH and also provides some advantages in terms of synthetic convergency. In the context of protected carbohydrates, the n-alkenyl moieties are also capable of acting as donors for glycosylation (see, for example, Fraser –Reid *et al.*, *SynLett*, **1992**, 927).

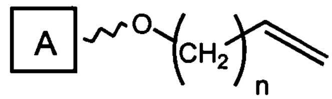
In this context, the present invention additionally provides methods for the synthesis of n-alkyl glycoamino acids, as described in more detail below for Globo-H and fucosyl GM1 and their subsequent use to generate glycopeptides and synthetic constructs thereof.

In general, the inventive method for the production of these glycoamino

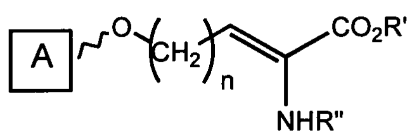
acids comprises: 1) providing an alkenyl glycosidic moiety, as described herein; 2) subjecting said alkenyl glycosidic moiety to oxidative conditions to generate an aldehyde; 3) subjecting said aldehyde to olefination conditions to generate an enamide ester; 4) subjecting said resulting enamide ester to conditions sufficient to hydrogenate said enamide ester to generate a protected glycoamino acid and 5) deprotecting said protected glycoamino acid under suitable conditions to generate a desired glycoamino acid.

In particular, a novel method for the synthesis of a glycoamino acid, the structure of which is set forth herein, is provided, which comprises the steps of:

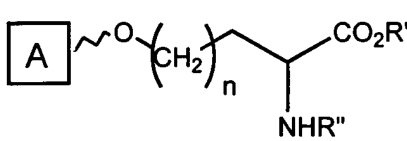
(a) providing an alkenyl glycoside having the structure:



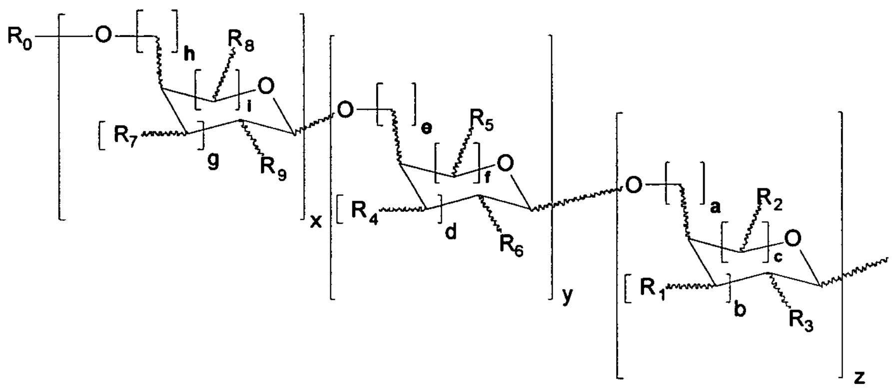
(b) reacting said alkenyl glycoside under suitable conditions to generate an enamide ester having the structure:



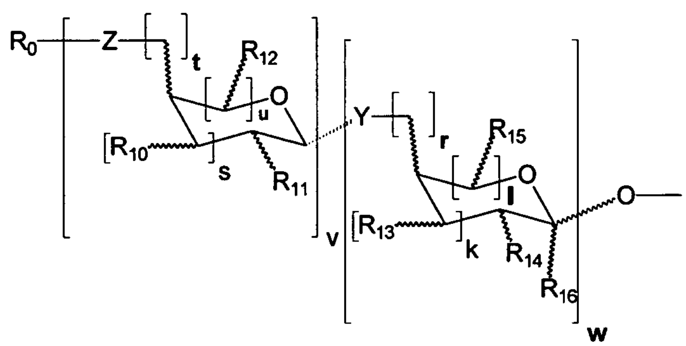
(b) reacting said enamide ester under suitable conditions to generate a glycoamino acid having the structure:



wherein, for each of the structures above, n is 0-8, wherein A is a carbohydrate domain having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4 , R_5, R_6 , R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$,

$CONHR^{ii}$, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group;

and wherein for the glycoamino acid structure R' and R" are each independently hydrogen, protecting group, substituted or unsubstituted alkyl, linker, aryl, peptide, protein or lipid; or NHR"', wherein R"' is a protein, peptide, or lipid, linked to N directly or through a crosslinker. In preferred embodiments, R' and R" are each independently hydrogen or a protecting group. In particularly preferred embodiments R" is a nitrogen protecting group, including, but not limited to, acetyl, Fmoc, Boc, and R' is an acid protecting group such as *t*-butyl or TSE. It will be appreciated, however, that a variety of protecting groups known in the art of organic synthesis can be employed, as referenced herein.

In certain preferred embodiments, the carbohydrate determinant is selected from the group consisting of Globo-H, fucosyl GM1, KH-1, glycophorin, STN, (2,3)ST, Le^y, N3, Tn, 2,6-STn, and TF. In other preferred embodiments, the carbohydrate determinant of the compound contains a Globo-H determinant or fucosyl GM1 determinant as all or part of the carbohydrate determinant A.

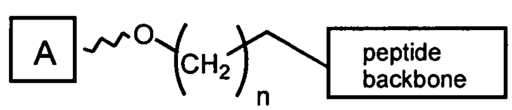
In general, in preferred embodiments, the step of reacting an n-alkenyl glycoside under suitable conditions to generate an enamide ester comprises reacting an n-alkenyl glycoside first under oxidative conditions and second under olefination conditions in the presence of base (e.g., tetramethylguanidine) and phosphonate to generate an enamide ester. It will be appreciated that other oxidative conditions known in the art of organic synthesis can be employed, including, but not limited to OsO_4 and periodate, or OsO_4 and $Pb(OAc)_4$. Additionally, other well-known bases can be utilized in the present invention, including, but not limited to, lithium t-butoxide or lithium hexamethyl disilylazide.

In preferred embodiments, reacting said enamide ester under suitable conditions to generate a glycoamino acid comprises reacting said enamide ester under hydrogenation conditions and subsequent reaction under deprotection conditions to generate a glycoamino acid. It is particularly preferred that the hydrgenation conditions employed

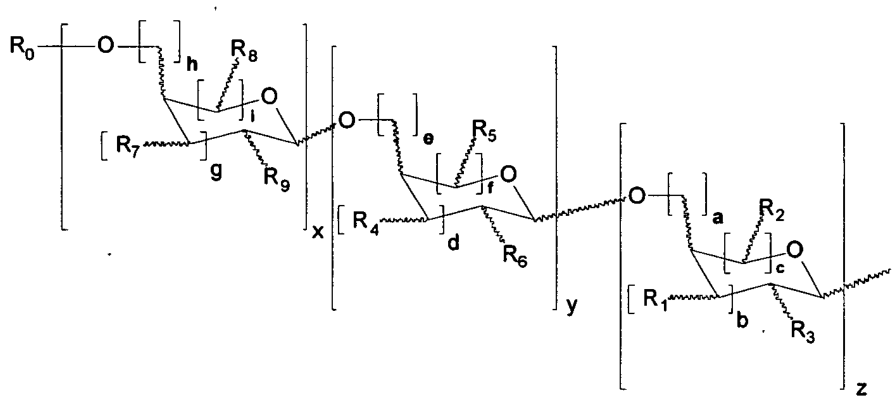
are asymmetric hydrogenation conditions. In a preferred embodiment, asymmetric hydrogenation can be achieved by utilizing an ethyl DuPHOS catalyst precursor, as described in more detail herein (see, Burk *et al. Accts. Chem. Res.* **2000**, *33*, 3631; Burk *et al. Pure & Appl. Chem.* **1996**, *68*, 37).

It will be appreciated that the ability to generate the glycoamino acids, as described herein, ultimately enables the synthesis of novel clustered glycopeptides, a motif commonly found on the surface of cancer cells (mucin-like structures) which are desirable for the uses described herein as anticancer vaccines. For example, immunological studies indicate that, in general, the clustering of antigens in glycopeptides results in a more therapeutically immune response than with singly glycosylated peptides (see, Lo-Man, R. *et al.*, *Cancer Res.*, **1999**, *59*, 1520; Reddish *et al.*, *Glycoconjugate J.* **1997**, *14*, 549).

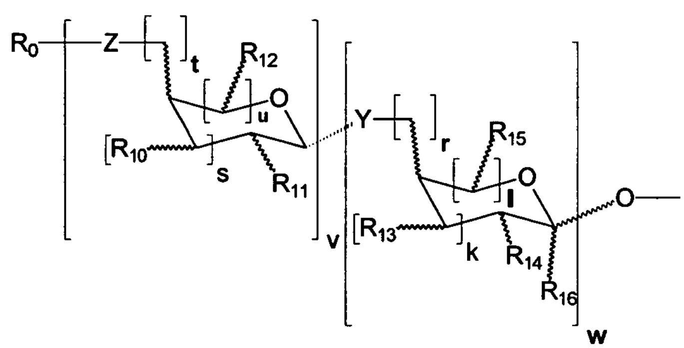
To date, the clustering of α-O-linked antigens has been accomplished with the same antigen across the peptide backbone via the traditional allyl linkage, as described in pending US patent numbers 09/083,776 and 09/276,595, the entire contents of which are hereby incorporated by reference. However, the present invention efficiently provides peptides having different antigens simultaneously in a clustered format. Thus, in one aspect, the present invention provides a multi-antigenic glycopeptide comprising a peptidic backbone made up of at least three glycoamino acids, wherein one or more of said amino acids are substituted with an n-alkyl glycosidic moiety having the structure:



wherein each occurrence of A is independently a carbohydrate determinant having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4 , R_5, R_6 , R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$, $CONHR^{ii}$, a substituted or unsubstituted linear or branched

chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group;

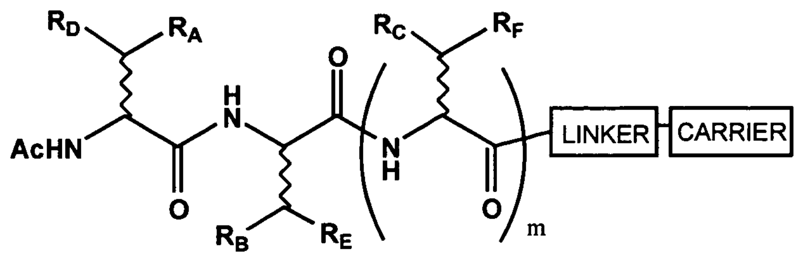
wherein each occurrence of n is independently 0-8, whereby, if for each occurrence of n, n = 0, at least one occurrence of A has a different structure from other occurrences of A; and wherein the n-alkyl glycosidic moiety is either α- or β-linked to an amino acid residue of the backbone. It will be appreciated that these inventive clustered glycopeptides are not limited to n-alkyl where n is greater than or equal to 1; rather multi-antigenic clustered glycopeptides can be linked via the traditional direct linkage (n=0) or via n-alkyl (such as pentyl) or any combination thereof. In preferred embodiments, each occurrence of A is independently selected from the group consisting of Globo-H, fucosyl GM1, KH-1, glycophorin, STN, (2,3)ST, Le^y, N3, Tn, 2,6-STn, and TF.

It will also be appreciated from the structure as set forth above, that, in addition to providing multi-antigenic structures, the present invention additionally provides clustered structures having n-alkyl linkages. Thus, in yet another aspect of the present invention, n-alkyl linked (where n is greater than or equal to 1) clustered glycopeptides are provided, which glycopeptides may incorporate multiple antigenic structures or may also incorporate all of the same antigenic structures.

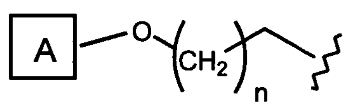
In general, the generation of the inventive glycopeptides comprises treating a first glycoamino acid with a deprotecting agent to reveal the corresponding carboxylic acid and then coupling said carboxylic acid under suitable conditions with a spacer moiety and a protecting group to generate a protected amide. A second glycoamino acid can then be coupled under standard conditions (e.g., BOP promoter or other known coupling reagents known in the art of peptide couplings) these couplings can be continued until a peptide of desired length is obtained. It will also be appreciated that solid phase methods of peptide synthesis known in the art can also be employed in the method of the present invention to generate the inventive glycopeptides.

While the glycopeptide of the present invention is not intended to be limited in size, in certain preferred embodiments, trimeric antigenic clusters are desirable and thus

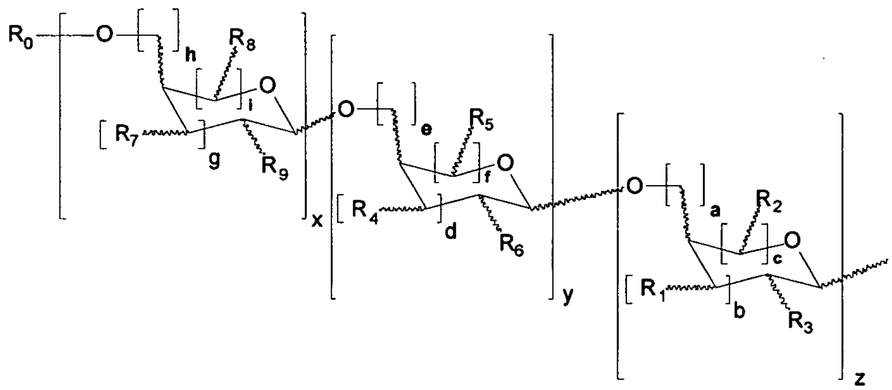
the present invention also provides constructs attached to a linker via a carrier protein having the following structure:



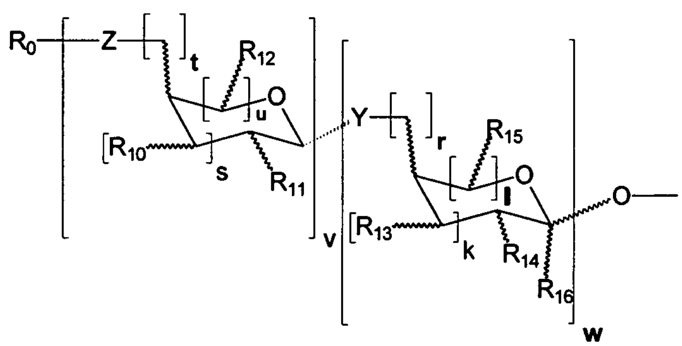
wherein the linker is either a free carboxylic acid, (carboxamido)alkyl carboxamide, MBS, primary carboxamide, mono- or dialkyl carboxamide, mono- or diarylcarboxamide, linear or branched chain (carboxy)alkyl carboxamide, linear or branched chain (alkoxycarbonyl)alkyl-carboxamide, linear or branched chain (carboxy)arylalkylcarboxamide, linear or branched chain (alkoxycarbonyl)alkylcarboxamide, an oligoester fragment comprising from 2 to about 20 hydroxy acyl residues, a peptidic fragment comprising from 2 to about 20 amino acyl residues, or a linear or branched chain alkyl or aryl carboxylic ester; wherein the carrier is a protein or lipid; wherein m is 1, 2 or 3; wherein R_A, R_B and R_C are each independently H or methyl; and wherein R_D, R_E and R_F are each independently an alkyl glycosidic moiety having the structure:



wherein each occurrence of A is independently selected from a carbohydrate domain having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein the carbohydrate domain is linked to the respective amino acyl or hydroxy acyl residue by substitution of a side group substituent selected from the group consisting of OH, COOH and NH_2; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4 , R_5, R_6 , R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a

substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$, $CONHR^{ii}$, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein each occurrence of n is independently 0-8, whereby, if for each occurrence of n, n = 0, at least one occurrence of A has a different structure from other occurrences of A; and wherein the n-alkyl glycosidic moiety is either α- or β-linked to an amino acid.

In certain embodiments, each occurrence of A is independently selected from the group consisting of Globo-H, fucosyl GM1, KH-1, glycophorin, STN, (2,3)-ST, Le^y, N3, Tn, 2,6-STn and TF. In but one preferred example, the present invention provides a novel trimeric antigenic glycopeptide incorporating globo-H, Le^y and Tn, to generate a novel trimeric antigenic compound, as described in more detail in Example 3 herein.

Pharmaceutical Compositions, Constructs and Uses Thereof

As described above, the present invention provides compounds and synthetic methodologies useful in the development of novel therapeutic agents, particularly for fully synthetic cancer vaccines. In general, the compounds and glycopeptides prepared as disclosed herein can be conjugated to a protein carrier or a lipid to generate useful glycoconjugates for the treatment and prevention, (preferably the prevention of the recurrence), of cancer in a subject suffering therefrom. In addition, glycoconjugates prepared by processes disclosed herein are antigens useful in adjuvant therapies as vaccines capable of inducing antibodies immunoreactive with various tumor cells. Such adjuvant therapies may reduce the rate of recurrence of certain cancers, and increase survival rates after surgery. Clinical trials on patients surgically treated for cancer who are then treated with vaccines prepared from a cell surface differentiation antigen found in patients lacking the antibody prior to immunization, a highly significant increase in disease-free interval may be observed. Cf. P.O. Livingston, *et al., J. Clin. Oncol.*, **1994**, *12*, 1036.

Thus, the present invention provides pharmaceutical compositions for treating cancer, preferably for preventing the recurrence of cancer, comprising any of the compounds of the present invention disclosed herein, as an active ingredient, optionally, though typically in combination with a pharmaceutically acceptable carrier. The pharmaceutical compostions of the present invention may further comprise other therapeutically active ingredients.

This method of treatment comprises administering to the subject a therapeutically effective amount of any of the glyconjugates disclosed herein, optionally in combination with a pharmaceutically acceptable carrier. The method may be applied wherein the cancer is a solid tumor or an epithelial tumor. As mentioned above, methods for the treatment of cancer (preferably for the prevention of recurrence of cancer) are provided, as well as methods for inducing antibodies in a human subject, wherein the antibodies are capable of specifically binding with human tumor cells, which comprises administering to the subject an amount of any of the glycoconjugates disclosed above effective to induce antibodies. In certain embodiments, the carbohydrate antigen is linked to an effective carrier either directly or through a crosslinker, which carrier is a protein or lipid. In certain embodiments, the carrier protein is bovine serine albumin, polylysine or KLH. In certain other embodiments, the lipid is PamCys.

In addition, the present invention provides the related method of inducing antibodies which further comprises co-administering an immunological adjuvant, or a combination of immunological adjuvants. In certain embodiments, the adjuvant is a saponin adjuvant (see, e.g., Marciani *et al.*, *Vaccine*, **2000**, *18*, 3141, US Patent No.: 6,080,725 and 5,977,081, the entire contents of which are hereby incorporated by reference). One example of a preferred saponin adjuvant includes, but is not limited to, GPI-0100, (Galenica Pharmaceuticals, Inc., Frederick, MD) which is a semi-synthetic adjuvant derived by modifying selected natural saponins. In certain other preferred embodiments, the adjuvant is bacteria or liposomes. In certain examples, the adjuvant includes but is not limited to, *Salmonella minnesota* cells, bacille Calmette-Guerin or QS21.

It will be appreciated that the magnitude of the therapeutic dose of the compounds of the invention will vary with the nature and severity of the condition to be treated and

with the particular compound and its route of administration. In general, the daily dose range for anticancer activity lies in the range of 0.0001 to 1.0 mg/kg of body weight in a mammal, although the present invention is not intended to be limited by this range.

Any suitable route of administration may be employed for providing a mammal, especially a human, with an effective dosage of a compound disclosed herein. For example, oral, rectal, topical, parenteral, ocular, pulmonary, nasal, etc. routes may be employed. Dosage forms include tablets, troches, dispersions, suspensions, solutions, capsules, creams, ointments, aerosols, etc. In preferred embodiments, the effective dosage is employed using a syringe injection.

The inventive compositions include those suitable for oral, rectal, topical (including transdermal devices, aerosols, creams, ointments, lotions and dusting powders), parenteral (including subcutaneous, intramuscular, and intravenous), ocular (opthalmic), pulmonary (nasal or buccal inhalation) or nasal administration. Although the most suitable route in any given case will depend largely on the nature and severity of the condition being treated and on the nature of the active ingredient. They may be conveniently presented in unit dosage form and prepared by any of the methods well known in the art of pharmacy.

In preparing oral dosage forms, any of the unusual pharmaceutical media may be used, such as water, glycols, oils, alcohols, flavoring agents, preservatives, coloring agents, and the like in the case of oral liquid preparations (e.g., suspensions, elixers and solutions); or carriers such as starches, sugars, microcrystalline cellulose, diluents, granulating agents, lubricants, binders, disinterating agents, etc., in the case of oral solid preparations are preferred over liquid oral preparations such as powders, capsules and tablets. If desired, capsules may be coated by standard aqueous or non-aqueous techniques. In addition to the dosage forms described above, the compounds of the invention may be administered by controlled release means and devices.

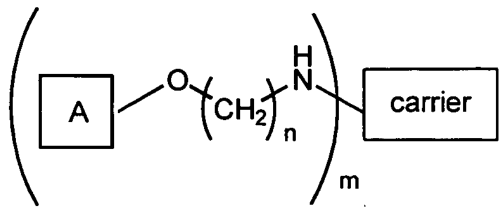
Pharmaceutical compositions of the present invention suitable for oral administration may be prepared as discrete units such as capsules, cachets or tablets each containing a predetermined amount of the active ingredient in powder or granular form or as a solution or suspension in an aqueous or nonaqueous liquid or in an oil-in-water or water-in-oil emulsion. Such compositions may be prepared by any of the methods known

in the art of pharmacy. In general, compositions are prepared by uniformly and intimately admixing the active ingredient with liquid carriers, finely divided solid carriers, or both and then, if necessary, shaping the product into the desired form. For example, a tablet may be prepared by compression or molding, optionally with one or more accessory ingredients. Compressed tablets may be prepared by compressing in a suitable machine the active ingredient in a free-flowing form such as a powder or granule optionally mixed with a binder, lubricant, inert diluent or surface active or dispersing agent. Molded tablets may be made by molding in a suitable machine, a mixture of the powdered compound moistened with an inert liquid diluent.

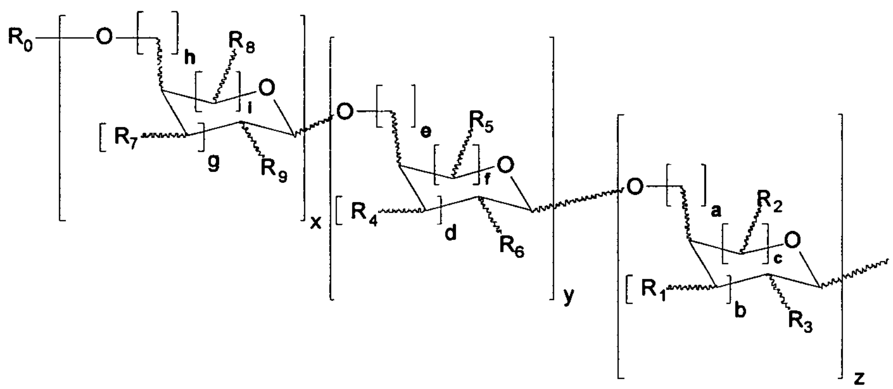
It will be appreciated by one of ordinary skill in the art, however, that the most suitable route for administration will depend largely on the nature and severity of the condition being treated and on the nature of the active ingredient. As discussed above, the inventive therapeutics may be conveniently presented in unit dosage form and prepared by any of the methods well known in the art of pharmacy.

As discussed above, in one embodiment of the present invention, the inventive n-alkenyl glycosides can be conjugated either directly or through a crosslinker to an appropriate carrier (e.g., KLH) to generate a synthetic tumor antigen. In general, a typical conjugation strategy that can be employed involves a reductive coupling of a glycoside which terminates in a glycoaldehyde, with the intended protein carrier, or lipid, presumably at the ε-amino acid residues of exposed lysines. (M.A. Bernstein; L.D. Hall, *Carbohydr. Res.* **1980**, *78*, C1; R.V. Lemieux *Chem. Soc. Rev.* **1978**, *7*, 423).

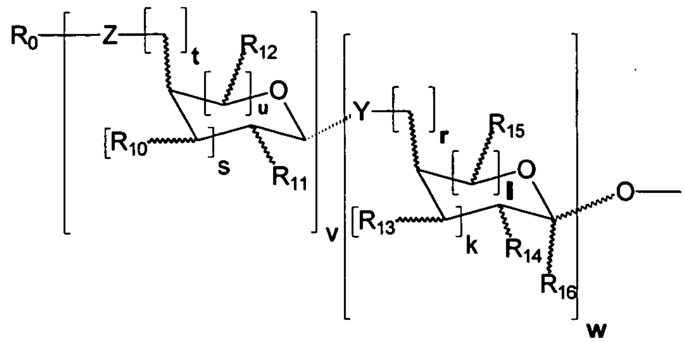
Thus, in another aspect, the present invention provides synthetic constructs, whereby novel antigenic structures, as described herein, are conjugated to carrier proteins, peptides or lipids. It will also be appreciated by one of ordinary skill in the art that, in the generation of a synthetic construct, more than one n-alkenyl moiety or glycopeptide moiety can ultimately be conjugated to a carrier protein to generate the synthetic vaccine. Thus, in addition to the conjugated glycopeptide structures as provided herein, constructs having the general structure as depicted below are also provided:



wherein A is a carbohydrate domain having the structure:



wherein a, b, c, d, e, f, g, h, i, x, y and z are independently 0, 1, 2 or 3, with the proviso that x, y and z are not simultaneously 0; wherein R_0 is hydrogen, a linear or branched chain alkyl, acyl, arylalkyl or aryl group; wherein R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8 and R_9 are each independently hydrogen, OH, OR^i, NH_2, $NHCOR^i$, F, CH_2OH, CH_2OR^i, a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R^i is hydrogen, CHO, $COOR^{ii}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group or a saccharide moiety having the structure:



wherein Y and Z are independently NH or O; wherein k, l, r, s, t, u, v and w are each independently 0, 1 or 2; wherein R_{10}, R_{11}, R_{12}, R_{13}, R_{14} and R_{15} are each independently hydrogen, OH, OR^{iii}, NH_2, $NHCOR^{iii}$, F, CH_2OH, CH_2OR^{iii}, or a substituted or unsubstituted linear or branched chain alkyl, (mono-, di- or tri)hydroxyalkyl, (mono-, di- or tri)acyloxyalkyl, arylalkyl or aryl group; wherein R_{16} is hydrogen, COOH, $COOR^{ii}$, $CONHR^{ii}$, a substituted or unsubstituted linear or branched chain alkyl or aryl group; wherein R^{iii} is hydrogen, CHO, $COOR^{iv}$, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group; and wherein R^{ii} and R^{iv} are each independently H, or a substituted or unsubstituted linear or branched chain alkyl, arylalkyl or aryl group;

wherein n is 0-8; wherein the carrier is a protein or lipid, including, but not limited to Bovine Serine Albumin, KLH and PamCys, wherein said protein or lipid is linked directly or though a crosslinker; and wherein m is in the range of 20-600. In certain preferred embodiments, n is 4. In certain other embodiments, m is in the range of 200-600. In still other preferred embodiments, the carbohydrate determinant is selected from the group consisting of Globo-H, KH-1, glycophorin, STN, (2,3)ST, N3, Tn, TF, 2,6-STn, and Le^y. In yet other preferred embodiments, the carbohydrate determinant is fucosyl GM1, which has the structure as depicted above, and as shown in Figure 1.

It will be appreciated that because certain of the inventive compounds produced terminate in an alkenyl linkage, in a typical protocol according to the present invention, conversion to an aldehyde is first required. Thus, in but one exemplary embodiment, an inventive synthetic globo-H tumor antigen is prepared from an n-alkenyl globo-H glycoside. As described in Example 2, this procedure involves exposing the n-alkenyl globo-H glycoside to oxidative conditions, in this case ozonolysis, followed by reductive

work-up to yield an aldehyde intermediate to generate a vaccine glycoconjugate. Subsequent hydrolytic carbohydrate analysis reveals approximately 350 carbohydrate residues/molecule of carrier protein, as described in Example 2.

In yet another example, a fucosyl GM1-KLH glycoconjugate is generated according to the method of the present invention, as discussed in Example 1. Notably, prior to conjugation studies, synthetic n-pentenyl fucosyl GM1 was shown to bind to monoclonal antibody F12 in ELISA and immune thin layer chromatography assays. Inhibition studies revealed that preincubation of F12 with antibody completely inhibits reactivity of natural fucosyl GM1, with the antibody. Clearly, the synthetic fucosyl GM1 pentenyl glycoside provides the antigenic epitope with which F12 reacts on SCLC cells.

Additionally, once a synthetic vaccine has been derivatized and characterized, mouse immunological studies can be performed to assess the potency and/or specificity of the novel tumor vaccines, as described in Example 4 herein.

Equivalents

The representative examples which follow are intended to help illustrate the invention, and are not intended to, nor should they be construed to, limit the scope of the invention. Indeed, various modifications of the invention and many further embodiments thereof, in addition to those shown and described herein, will become apparent to those skilled in the art from the full contents of this document, including the examples which follow and the references to the scientific and patent literature cited herein. In but one illustrative example, protecting groups play an important role in the synthesis of the carbohydrate domains and synthetic conjugates, as described herein; however it will be appreciated by one of ordinary skill in the art that the present invention encompasses the use of various alternate protecting groups known in the art. Those protecting groups used in the disclosure including the Examples below are merely illustrative.

It should further be appreciated that the contents of those cited references are incorporated herein by reference to help illustrate the state of the art. The following examples contain important additional information, exemplification and guidance which can be adapted to the practice of this invention in its various embodiments and the equivalents thereof.

Exemplification

A. Example 1: Synthesis of fucosyl GM1 pentenyl glycoside

1) Discussion of Synthesis:

As discussed above, in one aspect of the invention, the synthesis of fucosyl GM1 pentenyl glycoside is provided. In one embodiment of the present invention, this was achieved similarly to the methodology employed in the synthesis of MBr1 antigen, Globo-H (see, Park *et al., J. Am. Chem. Soc.* **1996**, *118*, 11488). For example, as shown in Figure 2, the synthesis of the ABC trisaccharide starting from the known protected lactal derivative **2**, was first undertaken (Kwon, O.; Danishefsky. S.J. *J. Am. Chem. Soc.* **1998**, *120*, 1588). Selective sialylation of the C3' equatorial hydroxyl in **2** proceeded smoothly with phosphite donor **3** (Sim *et al., J. Am. Chem. Soc.* **1993**, *115*, 2260; Chappell *et al., Tetrahedron* **1997**, *53*, 11109) to yield the glycal **4** as the only observable isomer in 75% yield. In addition, propionitrile was employed as the solvent because of the necessity to perform the reaction at low temperatures. Use of elevated temperatures in acetonitrile as the solvent resulted in diminished anomeric selectivity, regioselectivity and lower chemical yields. The key DEF trisaccharide was synthesized as previously described in the Globo-H synthesis (Park *et al. J. Am. Chem. Soc.* **1996**, *118,* 11488). The requisite thioethyl donor **5** is shown in Figure 2. Based on previous experience, it was expected that this specific donor would favor β-glycosidation via sulfonamido participation under the close guidance of the "proximal hydroxyl" directing effect (see asterisk) (see also, Park *et al. J. Am. Chem. Soc.* **1996**, *118*, 11488; Kwon *et al. J. Am. Chem. Soc.* **1998**, *120*, 1588), and the results confirmed this expectation. In an experiment directed at "proof of principle", reaction of **5** with 5.0 equivalents of MeOTf (Lonn, H. *Carbo. Res.* **1985**, *134*, 105; Lonn, H. *J. Carbohydr. Chem.* **1987**, *6*, 301) in the presence of **4** gave the desired hexasaccharide **6** in 23 % yield, as shown in Figure 3. Although direct deprotection of this compound was not achieved to yield the desired compound, in an effort to find a hexasaccharide which was suitable for global deprotection, replacement of the reducing end glycal was considered. Such a

replacement would also be potentially useful as a linker capable of being modified to allow for conjugation to a protein carrier or lipid.

In but one example, the use of a n-pentenyl glycoside was considered (For a review of n-pentenyl glycosides, see Fraser-Reid *et al.*, *Synlett*, **1992**, 927; Udodong *et al. J. Am. Chem. Soc.* **1993**, *115*, 7886; Merritt *et al. J. Am. Chem. Soc.* **1994**, *116*, 8334; Fraser-Reid *et al.* **1990**, *55*, 6068; Mootoo *et al. J. Am. Chem. Soc.* **1988**, *110*, 2662; Mootoo *et al. J. Am. Chem. Soc.* **1989**, *111*, 8540 and references therein). N-pentenyl glycosides are stable to a range of reaction conditions and reagents, but are readily activated for glycosidation reactions by treatment with a halogen oxidant. As a result of their stability and the neutral conditions required for their activation, pentenyl glycosides have been demonstrated to be valuable linkages for mechanistic and synthetic studies. Additionally, a terminal pentenyl group, or more generally a terminal alkenyl group, could also provide a handle for bioconjugation. Thus, in one embodiment, glycal **6a** was subjected to epoxidation under standard procedures with 3,3-dimethyldioxirane (Figure 3). Reaction with pentenyl alcohol and anhydrous zinc chloride (Gordon *et al. Carbohydrate Res.* **1990**, *206*, 361) afforded the glycoside **7** in 65% yield. Indeed, with the pentenyl glycoside in place, global deprotection of **7** was possible. The sequence shown in Figure 3 furnished the peracetylated hexasaccharide lactone **8** in 46 % yield (5 steps). Removal of the acetates with sodium methoxide followed by saponification of the resulting methyl ester yielded the target, fucosyl GM1 pentenyl glycoside, **1b**. The assignment of structure **1b** was based on ^{1}H and ^{13}C NMR analysis of **1b**, in conjunction with characterization of intermediates en route to the final structure, and is supported by high resolution mass spectrometry.

In yet another embodiment, in an effort to produce significant quantities of this epitope for pre-clinical, and eventually clinical evaluation, a more efficient synthetic route was developed utilizing a glycoside at the reducing end at the acceptor, rather than a glycal. As shown in Figure 4, pentenyl lactoside was first investigated. For this purpose, lactose octaacetate was converted to the known bromide **9** (Reithal, Y. *J. Am. Chem. Soc.* 1952, 74, 4210; Dasgupta *et al. Carbohydr. Res.* **1994**, *264*, 155). Reaction of this compound with pentenyl alcohol under promotion by silver carbonate delivered the desired pentenyl glycoside, **10**, on 100 g scale (Rodriguez, et al. *Aust. J. Chem.* **1990**,

43, 665). An analogous coupling to produce **9** using silver triflate as promoter resulted in only a 17% yield of the desired product. Removal of the acetates yielded lactoside **11**. Again, the C3' and C4' hydroxyl groups were engaged, this time as the dimethyl ketal **12**. This reaction, as currently conducted, was accompanied by formation of minor amounts of 4,6-acetonide (Catelani et al. *Carb. Res.* **1988**, *182*, 297). Perbenzylation of **12** to give **13** followed by acetonide removal with aqueous acetic acid yielded the desired AB acceptor **14**. Sialylation using phosphite donor **3** (Figure 2) proceeded in comparable yield to give trisaccharide acceptor, **15**.

Finally, turning to the desired fucosyl GM1, coupling of donor **5** with a 2.0 molar excess of the acceptor **15** containing the pentenyl linker proceeded with MeOTf promotion (1.5 equivalents x 2) in excellent yield (70%; see Figure 5). Global deprotection under identical conditions as in Figure 4, yielded the characterized hexasaccharide **1b**.

Attention was then directed to the final goal of developing a glycoconjugate. Synthetic **1b** was subjected to conjugation to carrier protein KLH, as depicted in Figure 6. The protocol started with ozonolysis, thereby producing the uncharacterized aldehyde derivative. This step was followed by coupling to KLH using reductive amination under the agency of sodium cyanoborohydride. Presumably coupling of the carbohydrate had occurred with the ε-amino group of lysine residues in the KLH. Hydrolytic carbohydrate analysis revealed approximately 331 carbohydrate residues per molecule of KLH to generate **1c**.

2) Experimentals

Peracetyl pentenyl-β-D-lactoside (10). To a cooled (ice bath) suspension of lactose octaacetate (100.0 g, 147.7 mmol), glacial acetic acid (30 mL) and acetic anhydride (30 mL) was added 100 mL of 30% HBr in AcOH dropwise over a period of 60 minutes. The reaction mixture stirred for 1 hour and the ice bath was removed. Upon stirring for an additional 2 hours at room temperature, the reaction became a homogeneous yellow solution. The solution was diluted with H_2O (1000 mL) and extracted with $CHCl_3$ (3x400 mL). The organic extracts were washed with H_2O (2x1000 mL), satd. $NaHCO_3$ (3x500 mL), dried over $MgSO_4$ and concentrated. The α-bromo

product **9** was azeotroped with anhydrous benzene and dried under high vacuum to yield 98.8 g (96%) of the lactosyl bromide which was used without further purification.

To a suspension of Ag_2CO_3 (100 g, 362.6 mmol), freshly activated molecular sieves (15 g) and a crystal of I_2 in 400 mL CH_2Cl_2 was added pentenyl alcohol (5.0 equiv., 73.4 mL) and then the lactosyl bromide **9** (98.8 g, 141.4 mmol) in 400 mL of CH_2Cl_2. After stirring in the dark at room temperature for 16 hours, the reaction was filtered through a plug of celite with additional CH_2Cl_2 and concentrated to a yellow oil which was purified by flash column chromatography (10% EtOAc/hexanes->50% EtOAc/hexanes) to yield 74.7 g (75%) of the pentenyl lactoside **10** as a white foam. $[\alpha]^{22}{}_D$ –48.9° (*c* 7.5, $CHCl_3$); IR (film $CHCl_3$) 2941, 1751, 1369, 1224, 1054 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.60 (m, 1H), 5.17 (d, 1H, J=2.7 Hz), 5.02 (m, 1H), 4.93 (dd, 1H, J=7.9, 10.3 Hz), 4.85 (d, 1H, J=1.6 Hz), 4.78 (m, 2H), 4.71 (dd, 1H, J=9.6, 7.9 Hz), 4.30 (m, 3H), 3.93 (m, 3H), 3.66 (m, 3H), 3.45 (m, 1H), 3.30 (m, 1H), 1.98 (s, 3H), 1.94 (s, 3H), 1.91 (m, 2H), 1.89 (s, 3H), 1.88 (s, 6H, $2xCH_3$), 1.87 (s, 3H), 1.79 (s, 3H), 1.49 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.33, 170.28, 170.09, 170.00, 169.74, 69.54, 169.01, 137.72, 115.00, 101.01, 100.51, 76.27, 72.76, 72.48, 71.64, 70.94, 70.58, 69.23, 69.01, 66.52, 61.97, 60.73, 29.75, 28.49, 20.80, 20.75, 20.64, 20.57, 20.45; HRMS (FAB) cald. for $C_{31}H_{44}O_{18}Na$ $[M+Na]^+$ 727.2425, found 727.2418.

Pent-4-enyl 3', 4'-*O*-acetonide-β-D-lactoside (12). Peracteylated pentenyl lactoside, **10**, (18.2 g, 25.8 mmol) was dissolved in 300 mL of anhydrous MeOH and 2.0 mL of NaOMe (25% in MeOH) was added. The reaction stirred at rt for 16 hours and was neutralized with Dowex-H^+ (pH 5-6). The reaction was filtered with additional MeOH and concentrated to a white solid (10.6 g, quantitative) which was used without further purification. Pentenyl-β-D-lactoside **11**: ^1H NMR (D_2O, 400 MHz) δ 5.81 (m, 1H), 5.00 (dd, 1H, J=17.3, 1.9 Hz), 4.92 (dd, 1H, J=8.9 Hz), 4.74 (m, 1H), 4.39 (d, 1H, J=8.0 Hz), 4.35 (d, 1H, J=7.8 Hz), 3.72-3.42 (m, 12H), 3.21 (m, 1H0, 2.06 (m, 2H), 1.63 (m, 2H); ^{13}C NMR (D_2O, 100 MHz) δ 141.27, 117.31, 105.42, 104.54, 80.85, 77.84, 77.24, 76.92, 75.33, 75.00, 73.44, 72.47, 71.03, 63.52, 62.56, 31.83, 30.48.

To pentenyl lactoside **11** (10.6 g, 25.8 mmol) was added 200 mL acetone, 26 mL of dimethoxypropane and *p*-toluenesulfonic acid (491 mg, 0.1 equiv.). The suspension stirred at room temperature overnight at which point the reaction was homogeneous. The reaction was concentrated and purified by flash column chromatography (100% EtOAc -> 2%MeOH in EtOAc) to give 5.1 g (44%) of the 3,4-acetonide as a white solid and 1.27 g of the 4,6-acetonide as a white solid. **3,4-acetonide, 12:** $[\alpha]^{22}_D$ 79.0° (0.96*c* , MeOH); IR 3422, 2980, 2933, 2870, 1242, 1073 cm^{-1}; ^1H NMR (MeOH, 400 MHz) δ 5.83 (m, 1H), 5.00 (dd, 1H, J=17.1, 3.4 Hz), 4.92 (dd, 1H, J=10.2, 2.0 Hz), 4.34 (d, 1H, J=8.2 Hz), 4.25 (d, 1H, J=7.8 Hz), 4.17 (dd, 1H, J=5.5, 2.1 Hz), 4.02 (dd, 1H, J=7.2, 5.5 Hz), 3.91 (m, 3H), 3.88-3.73 (m, 5H), 3.55-3.47 (m, 3H), 3.42 (m, 1H), 3.38 (m, 1H), 3.21 (m, 1H), 2.13 (m, 2H), 1.67 (m, 2H), 1.45 (s, 3H), 1.30 (m, 3H); ^{13}C NMR (MeOH, 100 MHz) δ 139.42, 115.20, 111.04 (O-C-O), 104.16, 104.09, 80.94, 80.77, 76.29, 76.25, 75.27, 75.00, 74.76, 74.39, 62.36, 61.82, 31.18 (CH_3), 30.02, 28.41, 26.51 (CH_3); HRMS (Fab) cald. for $C_{20}H_{34}O_{11}Na$ $[M+Na]^+$ 473.1998, found 473.1985. **4,6-acetonide:** $[\alpha]^{22}_D$ -216.0 ° (*c* 1.14, MeOH); IR 3364, 2926, 2870, 1380 cm^{-1}; ^1H NMR (MeOH, 400 MHz) δ 5.79 (m, 1H), 4.98 (dd, 1H, J=17.0, 1.8), 4.90 (dd, 1H, J=10.2, 1.0), 4.35 (d, 1H, J-7.8 Hz), 4.24 (d, 1H, J=7.8 Hz), 4.13 (m, 2H), 3.86-3.82 (m, 3H), 3.76 (dd, 1H, J=12.9, 1.4 Hz), 3.61-3.49 (m, 5H), 3.44 (s, 1H), 3.35 (m, 1H), 3.19 (t, 1H), 2.11 (m, 2H), 1.66 (m, 2H), 1.43 (s, 3H), 1.35 (s, 3H); ^{13}C NMR (MeOH, 100 MHz) δ 139.48, 115.20, 104.68, 104.26, 100.17 (O-C-O), 79.86, 76.40, 76.35, 74.81, 73.34, 71.46 ,70.25, 69.95, 68.04, 63.67, 61.69, 31.23 (CH_3), 30.08, 29.56, 18.69 (CH_3).

Pent-4-enyl 2, 3, 6, 2', 6'-penta-*O*-benzyl-3', 4'-*O*-acetonide-β-D-lactoside (13). The acetonide **12** (3.40 g, 7.54 mmol) was azeotroped with anhydrous benzene, dissolved in anhydrous DMF (60 mL, 0.12 M) and cooled to 0 °C. Benzyl bromide (passed through basic alumina, 10.0 equiv. 8.97 mL), was added followed by solid NaH (95%, 7.5 equiv., 1.76 g) in one portion. The reaction was allowed to warm to room temperature overnight and then poured into ice cold H_2O (500 mL) and extracted with $CHCl_3$ (200 mL, 2x100mL). The organic extracts were washed with brine (500 mL), dried over $MgSO_4$ and concentrated to a yellow oil which was purified by flash column chromatography

(5% EtOAc/hexanes -> 20% EtOAc/hexanes) to yield 5.70 g (84%) of the product as a viscous oil. $[\alpha]^{22}_D$ 196.0° (1.09*c* , $CHCl_3$); IR (film $CHCl_3$) 3062, 3029, 2868, 1367, 1093, 1055 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.39-7.20 (m, 25H), 5.78 (m, 1H), 4.98 (dd, 1H, J=17.1, 3.4 Hz), 4.93 (dd, 1H, J=10.2, 2.0 Hz), 4.89 (d, 1H, J=10.6 Hz), 4.86 (d, 1H, J=10.9 Hz), 4.75 (d, 1H, J=11.7 Hz), 4.70 (d, 1H, J=10.6 Hz), 4.68 (d, 1H, J=10.8 Hz), 4.63 (d, 1H, 11.8 Hz), 4.53 (d, 1H, J=12.1 Hz), 4.46 (d, 1H, J=12.1 Hz), 4.39 (d, 1H, J=6.3 Hz), 4.36 (d, 1H, J=2.0 Hz), 4.34 (d, 1H, J=7.8 Hz), 4.28 (d, 1H, J=12.0 Hz), 4.07 (dd, 1H, J=5.5, 1.4 Hz), 3.99 (m, 1H), 3.91 (m, 2H), 3.76 (dd, 1H, J=11.9, 4.2 Hz), 3.70 (dd, 1H, J=10.8, 1.6 Hz), 3.65 (m, 2H), 3.55-3.47 (m, 3H), 3.35 (m, 2H), 3.30 (dd, 1H, J=7.9, 0.8 Hz), 2.31 (m, 2H), 1.72 (m, 2H), 1.36 (s, 3H), 1.31 (s, 3H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.92, 138.54, 138.43, 138.31, 138.19, 138.00, 128.22, 128.16, 128.08, 127.99, 127.95, 127.77, 127.63, 127.49, 127.40, 127.34, 127.20, 114.83, 109.66, 103.56, 101.76, 82.89, 81.75, 80.53, 79.26, 76.30, 75.32, 74.96, 74.91, 73.51, 73.28, 73.12, 73.08, 71.86, 69.16, 68.82, 68.18, 30.15, 28.87, 27.89, 26.34; HRMS (FAB) cald. for $[M+Na]^+$ $C_{55}H_{64}O_{11}Na$ 923.4346, found 923.4330.

Pent-4-enyl 2, 3, 6, 2', 6'-penta-*O*-benzyl-β-D-lactoside (14). The acetonide **13** (5.7 g, 6.32 mmol) was dissolved in 80% AcOH in H_2O (60 mL) and heated to 75 °C for 3 hours. The reaction was cooled to rt, diluted with H_2O (500 mL) and extracted with $CHCl_3$ (200 mL, 2x100 mL). The organic extracts were washed with H_2O (500 mL), satd. $NaHCO_3$ (3x300 mL), dried over $MgSO_4$ and concentrated to an oil which was purified by flash column chromatography (25% EtOAc/hexanes) to yield 5.21 g (96%) of a white solid. $[\alpha]^{22}_D$ 194.1° (1.13*c* , $CHCl_3$); IR (film $CHCl_3$) 3444, 3028, 2868, 1091, 1058 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.41-7.20 (m, 25H), 5.74 (m, 1H), 4.96-4.88 (m, 3H), 4.82 (d, 1H, J=10.9 Hz), 4.72 (d, 1H, J=11.4 Hz), 4.70 (d, 1H, J=10.9 Hz), 4.64 (d, 1H, J=10.9 Hz), 4.58 (d, 1H, J=11.6 Hz), 4.52 (d, 1H, J=10.9), 4.38-4.28 (m, 5H), 3.93-3.85 (m, 3H), 3.71 (m, 2H), 3.55-3.40 (m, 4H), 3.36 (m, 3H), 3.28 (m, 2H), 2.48 (d, OH, 1H, J=3.2 Hz), 2.40 (s, OH, 1H), 2.09 (m, 2H), 1.66 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 139.09, 138.53, 139.29, 138.17, 138.01, 137.91, 128.44, 128.35, 128.24, 127.89, 127.82, 127.77, 127.63, 127.55, 127.19, 114.86, 103.57, 102.53, 82.76, 81.71,

79.96, 76.57, 75.17, 75.02, 74.89, 74.80, 73.45, 73.40, 73.12, 72.79, 69.22, 68.71, 68.60, 68.24, 30.17, 28.88; HRMS (FAB) cald. for $C_{52}H_{60}O_{11}Na$ $[M+Na]^+$883.4033, found 883.4017.

Trisaccharide 15. The phosphite donor **3** (1.0 g, 1.35 mmmol) and lactosyl acceptor **14** (2.5 g, 2.90 mmol) were combined, azeotroped with anhydrous benzene and placed under high vacuum for 2 hours. The mixture was dissolved in anhydrous CH_3CH_2CN (distilled from CaH_2), freshly activated molecular sieves were added and the reaction cooled to -40 °C. A portion of TMSOTf (0.1 equiv., 27μL) was added and the reaction was allowed to stir at -40 °C overnight. The reaction was then warmed to -30 °C and another 0.1 equivalent of TMSOTf was added. Upon stirring for an additional 2 hours at -30 °C, the reaction was quenched by the addition of solid $NaHCO_3$ and was filtered through a plug of celite with the aid of EtOAc. The organic layer was washed with satd. $NaHCO_3$ (2x400 mL) and dried over $MgSO_4$. Evaporation of organic layer gave a cloudy oil which was subjected to flash column chromatography using careful gradient elution in order to recover acceptor and product trisaccharide (20% EtOAc/hexanes -> 75% EtOAc/hexanes). The product (1.35g, 75%) was obtained as a white foam and 0.95 g of starting acceptor was recovered. : $[\alpha]^{22}_D$ 2.38° (*c* 1.30, $CHCl_3$); IR (film $CHCl_3$) 3106, 2866, 1744, 1689, 1368, 1222, 1055 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.40-7.17 (m, 25H), 5.79 (m, 1H), 5.38 (m, 1H), 5.27 (dd, 1H, J=8.0, 2.0 Hz), 5.08 (d, 1H, J=10.0 Hz), 4.95 (m, 3H), 4.86 (d, 1H, J=10.9 Hz), 4.75 (d, 1H, J=5.7 Hz), 4.72 (d, 1H, J=10.8 Hz), 4.68 (d, 1H, J=11.0 Hz), 4.56 (d, 1H, J=11.9 Hz), 4.54 (d, 1H, J=7.6 Hz), 4.44 (d, 1H, J=12.2 Hz), 4.39 (m, 1H), 4.32-4.25 (m, 3H), 4.06-3.88 (m, 6H), 3.79 (m, 2H), 3.72 (s, 3H), 3.65 (m, 3H), 3.54-3.44 (m, 5H), 3.35 (m, 2H), 2.66 (d, OH, 1H, J=3.3 Hz), 2.47 (dd, 1H, J=13.0, 4.7 Hz), 2.12 (m, 2H), 2.06 (s, 3H), 2.02 (m, 1H), 1.98 (s, 3H), 1.95 (s, 3H),1.85 (s, 3H), 1.83 (s, 3H), 1.71 (s, 3H) ; ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.77, 170.53, 170.23, 169.92, 169.87, 168.32, 139.09, 138.90, 138.61, 138.45, 138.34, 138.05, 128.27, 128.21, 137.99, 127.51, 127.42, 127.11, 114.81, 103.48, 102.29, 98.32, 82.90, 81.80, 78.37, 76.50, 76.30, 75.31, 75.01, 74.89, 74.82, 73.23, 72.97, 72.66, 72.37, 69.16, 69.03, 68.69, 68.43, 68.36, 67.81, 67.08, 62.21, 52.99, 49.17, 36.41, 30.17, 28.89, 23.11,

21.08, 20.77, 60.67, 60.47; HRMS (FAB) cald. for $C_{72}H_{87}NO_{23}Na$ ($M+Na^{+}$) 1356.5566, found 1356.5557.

Hexasaccharide 7 (R=Bn). The thioethyl donor **5** (311 mg, 0.243 mmol) and acceptor **15** (627 mg, 0.487 mmol) were combined, azeotroped with anhydrous benzene (5x5 mL) and placed under high vacuum for 5 hours. The mixture was then dissolved in 1.6 mL CH_2Cl_2 and 3.2 mL Et_2O (0.05M total), treated with freshly prepared molecular sieves and cooled to 0 °C. Methyl triflate (1.5 equiv., 41 μL) was added in one portion and the reaction stirred at 0 °C overnight. In the morning, another 20 μL of MeOTf was added and the reaction was allowed to stir for an additional 2 hours at 5 °C. The reaction was quenched by the addition of solid $NaHCO_3$, filtered through celite with EtOAc, concentrated and purified by flash column chromatography (gradient elution 25% EtOAc/hexanes -> 50% -> 75% EtOAc/hexanes) to give 437 mg (70%) of hexasaccharide as a white foam and 300 mg of recovered trisaccharide accpetor: $[\alpha]^{22}_{D}$ -29.4° (*c* 3.25, $CHCl_3$); IR (film $CHCl_3$) 3285, 3028, 2940, 2865, 1794, 1749, 1690, 1220, 1090 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.74 (d, 2H, J=7.5 Hz), 7.34-7.08 (m, 43H), 5.75 (m, 1H), 5.52 (d, 1H, J=4.7 Hz), 5.29 (app s, 1H), 5.23 (dd, 1H, J=9.5, 1.4 Hz), 5.15 (m, 1H), 5.02 (d, 1H, J=9.8 Hz)4.97-4.87 (m, 5H), 4.84 (d, 1H, J=10.9 Hz), 4.81-4.70 (m, 5H), 4.63 (d, 1H, J=11.6 Hz), 4.57 (m, 3H), 4.44 (d, 1H, J=7.2 Hz), 4.40 (d, 1H, J=12.2 Hz), 4.30 (d, 1H, J=7.8 Hz), 4.10 (m, 2H), 3.98-3.81 (m, 12H), 3.82 (s, 3H), 3.78-3.68 (m, 7H), 3.64-3.45 (m, 8H), 3.27 (m, 3H), 3.17 (dd, 1H), 2.80 (d, OH, 1H, J=2.1 Hz), 2.19 (dd, 1H, J=13.0, 4.5 Hz), 2.10 (m, 3H), 2.01 (s, 3H), 1.92 (s, 3H), 1.88 (s, 3H), 1.82 (s, 3H), 1.81 (s, 3H), 1.68 (m, 2H), 1.08 (d, 3H, J=5.4 Hz), 1.00-0.92 (m, 42H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.61, 170.34, 170.26, 169.66, 167.78, 155.48, 138.95, 138.65, 138.63, 138.56, 138.42, 138.38, 138.27, 138.05, 132.17, 129.02, 128.59, 128.46, 128.18, 128.05, 127.91, 127.63, 127.51, 127.24, 127.09, 114.80, 103.42, 102.76, 102.45, 100.16, 99.58, 98.76, 82.87, 81.53, 79.06, 77.32, 77.24, 77.16, 75.12, 75.07, 74.95, 74.80, 73.92, 73.27, 73.04, 72.93, 72.19, 69.23, 69.14, 69.09, 67.89, 67.53, 61.76, 61.58, 61.12, 56.39, 53.60, 49.19, 35.36, 30.17, 28.89, 23.13, 20.97, 20.75, 20.62, 20.53,

17.85, 17.53, 17.33, 16.72, 11.80, 11.74; HRMS (FAB) cald. for $C_{136}H_{178}N_2O_{39}SSi_2$ ($M+Na^+$) 2574.1163, found 2574.1130.

Compound 1b. To a solution of the hexasaccharide (130 mg, 0.0509 mmol) in THF (2.0 mL) was added glacial AcOH (10.0 equiv., 29 μL) and TBAF (1.0 M THF, 10.0 equiv., 0.509 mL). The reaction stirred at rt overnight, was poured into ice water and extracted with EtOAc (3x50 mL). The organic extracts were washed with satd. $NaHCO_3$ (50 mL) and brine (50 mL), dried over $MgSO_4$ and concentrated to an oil which was purified through a short plug of silica gel with EtOAc. The resulting triol was dissolved in anhydrous MeOH (2.5 mL) and sodium methoxide was added (0.250 mL of a 25% solution in MeOH). The reaction stirred at rt for 18 hours and then 0.5 mL of THF and 0.5 mL of H_2O were added. Stirring at rt for an additional 24 hours was followed by neutralization with Dowex-H^+, filtration with MeOH washings and concentration. The crude material was allowed to dry under high vacuum for 1 day. To the resulting white solid was added THF (0.5 mL) and condensed liquid NH_3 (~10 mL) at -78 °C. Sodium (~50 mg) was added and the resulting blue solution stirred at -78 °C for 1.5 hours. The reaction was quenched with anhydrous MeOH (~5 mL), brought to rt and concentrated with a stream of dry N_2 to a volume of ~ 2 mL. The reaction was neutralized with Dowex-H^+, filtered with MeOH washings and concnetrated to a white solid. The white solid was dissolved in 1.0 mL pyridine and 1.0 mL CH_2Cl_2 and cooled to 0 °C. A crystal of DMAP was added followed by acetic anhydride (1.0 mL). The ice bath was removed and the reaction stirred at rt overnight. Concentration followed by purification by flash column chromatography (gradient elution 75% EtOAc/hexanes -> 100% EtOAc -:> 5% MeOH/EtOAc) gave 44 mg (46%) of **8** as a white solid: ^1H NMR (MeOH, 400 MHz) δ 8.02 (d, 1H, J=9.9 Hz), 7.87 (d, 1H, J=9.2 Hz), 5.76 (m, 1H), 5.49 (m, 1H), 5.39 (d, 1H, J=2.9 Hz), 5.34-5.31 (m, 2H), 5.22 (d, 1H, J=3.4 Hz), 5.19 (d, 1H, J=4.1 Hz), 5.17 (d, 1H, J=3.5 Hz), 5.12-5.05 (m, 3H), 4.97 (dd, 1H, J=16.8, 1.7 Hz), 4.91 (dd, 1H, J=10.0, 1.7 Hz), 4.81-4.75 (m, 3H), 4.65-4.60 (m, 2H), 4.52 (d, 1H, J=7.9 Hz), 4.48-4.44 (m, 2H), 4.37 (dd, 1H, J=10.0, 2.5 Hz), 4.28 (dd, 1H, J=12.5, 2.4 Hz), 4.22-4.18 (m, 2H), 4.14-3.99 (m, 9H), 3.96-3.92 (m, 2H), 3.89 (d, 1H, J=2.9 Hz), 3.88-3.77 (m, 4H), 3.72-3.62 (m, 3H), 3.51-3.45 (m, 1H), 2.74 (dd, 1H, J=11.3, 4.5 Hz), 2.19 (s, 3H), 2.13 (s, 3H),

2.11 (s, 3H), 2.10 (s, 3H), 2.09 (s, 3H), 2.08 (s, 3H), 2.06 (s, 3H), 2.05 (s, 3H), 2.02 (s, 3H), 2.01 (s, 3H), 2.00 (s, 3H), 1.99 (s, 3H), 1.98 (s, 3H), 1.97 (s, 3H), 1.95 (s, 3H), 1.94 (s, 3H), .91 (s, 3H), .180 (s, 3H), 1.61 (m, 2H), 1.14 (d, 3H, J=6.4 Hz), 3 protons burried beneath acetates (2 Pn, 1 C3ax); ^{13}C NMR (MeOH, 100 MHz) δ 174.64, 173.64, 172.98, 172.89, 172.63, 172.56, 172.48, 172.44, 172.34, 172.27, 172.04, 171.99, 171.76, 171.73, 171.62, 171.35, 171.25, 139.23, 115.47, 104.62, 103.26, 101.86, 101.63, 100.78, 97.31, 78.22, 76.53, 75.08, 74.69, 74.29, 73.91, 73.53, 72.94, 72.71, 72.56, 72.16, 72.06, 71.89, 71.74, 70.19, 69.87, 69.33, 69.11, 68.92, 65.96, 65.65, 63.68, 63.52, 62.69, 54.01, 53.09, 50.60, 40.19, 31.09, 29.96, 24.17, 24.06, 22.73, 21.76, 21.59, 21.46, 21.20, 21.06, 20.89, 20.75, 20.63, 20.55, 16.52.

The peracetate (40 mg) was dissolved in anhydrous MeOH (2.0 mL) and 150 μL of sodium methoxide was added (25% solution in MeOH). The reaction stirred at rt for 18 hours and then 0.5 mL of THF and 0.5 mL of H_2O was added. The reaction stirred for another 24 hours at rt. Neutralization with Dowex-H^+ (~pH 6-7) was followed by filtration with MeOH washings, concentration and purification using P-2 Gel (H_2O elutent) to yield 24 mg (96%) of a white solid: IR 3346, 2940, 2882, 1657, 1620, 1376, 1069 cm^{-1}; ^{1}H NMR (D_2O, 400 MHz) δ 5.86 (m, 1H), 5.18 (d, 1H, J=4.0 Hz), 5.04 (dd, 1H, J=17.22, 1.7 Hz), 4.97 (dd, 1H, J=10.6 Hz), 4.63 (d, 1H, J=7.6 Hz), 4.57 (d, 1H, J=7.7), 4.46 (d, 1H, J=7.9 Hz), 4.43 (d, 1H, J=8.1 Hz), 4.15 (m, 1H), 4.09-4.02 (m, 3H), 3.94-3.84 (m, 5H), 3.80-3.63 (m, 18H), 3.60-3.53 (m, 6H), 3.47 (dd, 1H, J=10.3, 1.8), 3.32 (t, 1H), 3.26 (t, 2H), 2.62 (dd, 1H, J=13.4, 4.3 Hz), 2.09 (m, 2H), 1.98 (s, 6H), 1.86 (m, 1H), 1.67 (m, 2H), 1.15 (d, 3H, J=6.5 Hz) ; ^{13}C NMR (D_2O, 100 MHz) δ 176.29, 175.43, 175.16, 139.97, 115.99, 104.38, 103.77, 103.30, 103.22, 102.25, 100.35, 79.67, 78.12, 77.65, 77.03, 76.06, 75.94, 75.62, 75.44, 75.24, 74.85, 74.19, 74.01, 73.45, 73.01, 71.15, 70.72, 70.32, 69.87, 69.64, 69.25, 67.93, 64.01, 62.29, 62.07, 61.63, 61.29, 52.79, 52.70, 50.04, 38.45, 30.53, 29.17, 23.89, 23.23, 16.53; HRMS (FAB) cald. for $C_{48}H_{79}N_2O_{33}Na_2$ [M-H+2Na]$^+$ 1257.4360, found 1257.4337.

Glycal hexasaccharide 6a. The thioethyl donor **5** (120 mg, 0.0938 mmol) and acceptor **4** (122 mg, 0.108 mmol) were combined, azeotroped with anhydrous benzene (5x5mL) and placed under high vacuum overnight. The mixture was dissloved in a 2:1 mixture of

$Et_2O:CH_2Cl_2$ (2.7 mL total), molecular sieves were added and the mixture stirred at rt for 1 h. The reaction was cooled to 0 °C and 1.0 equiv. of MeOTf (0.020 mL) was added. After 4 hours at 0 °C another equivalent of MeOTf was added (0.020mL) and the reaction continued to stir for another 4 h at 10 °C. The reaction was quenched with solid $NaHCO_3$, filtered through celite with additional EtOAc (100ml) and concentrated. The resulting mixture was purified by flash column chromatography to give 50 mg (23%) of the hexasaccharide glycal **6** and 85 mg of starting acceptor, **4**: R_f 0.35 (66% EtOAc/hexanes); ^1H NMR (500 MHz, C_6D_6) δ 8.31 (d, 2H), 7.62 (d, 2H), 7.52 (m, 4H), 7.45 (d, 2H), 7.40-7.15 (m, 31H), 6.47 (d, 1H, J=6.3 Hz), 6.28 (apparent s, 1H), 6.09 (d, 1H, J=3.8 Hz), 5.72 (m, 1H), 5.55 (dd, 1H, J=9.3, 1.2 Hz), 5.51 (d, 1H, J=3.5 Hz), 5.22 (d, 1H, J=10.8 Hz), 5.15 (s, 1H), 5.13-5.06 (m, 3H), 5.05 (d, 1H, J=8.1 Hz), 5.02 (m, 1H), 4.98 (d, 1H, J=10.8 Hz), 4.85 (d, 1H, J=10.6 Hz), 4.82 (d, 1H, J=9.4 Hz), 4.73-4.66 (m, 8H), 4.55-4.34 (m, 10H), 4.38-4.32 (m, 5H), 4.30 (d, 1H), 4.18 (s, 3H), 4.21-4.12 (m, 6H), 4.06 (m, 2H), 3.99 (m, 4H), 3.85 (d, 1H), 3.74 (dd, 1H), 3.61 (m, 2H), 3.52 (t, 1H), 2.63 (dd, 1H, J=13.9, 5.0), 2.48 (dd, 1H, J=13.4 Hz), 2.35 (s, 3H), 2.01 (s, 3H), 1.98 (s, 3H), 1.72 (s, 3H), 1.64 (s, 3H), 1.57 (d, 3H, J=6.3), 1.31-1.20 (m, 42H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 169.71, 169.39, 169.18, 168.70, 168.12, 166.99, 154.75, 143.47, 137.81, 137.71, 137.51, 137.42, 137.07, 131.65, 128.25, 127.52, 128.32, 127.26, 127.23, 127.19, 127.10, 126.98, 126.91, 126.83, 126.73, 126.62, 126.53, 126.36, 126.29, 101.67, 101.35, 98.69, 98.32, 98.26, 97.33, 80.48, 78.05, 77.06, 76.20, 75.50, 74.64, 74.22, 73.87, 73.49, 72.90, 72.38, 72.26, 71.93, 71.47, 71.20, 70.34, 70.17, 69.99, 69.13, 68.62, 68.10, 67.92, 67.01, 66.88, 66.68, 65.52, 60.92, 60.61, 55.51, 52.59, 48.31, 34.87, 28.68, 22.19, 19.95, 19.77, 19.68, 19.59, 16.93, 16.88, 15.79, 10.86, 10.78; HRMS (FAB) cald. for $C_{124}H_{162}N_2O_{37}Si_2SNa$ $[M+Na]^+$ 2382.0013, found 2382.0001.

Imido-hexasaccharide 6b Performing the above reaction with 10 equiv. MeOTf added in one portion, under otherwise identical conditions yields 28% of the following compound, which is much less polar than the parent N-acetylated hexasaccharide **6a**. R_f 0.35 (25% EtOAc/hexanes); ^1H NMR (500 MHz, C_6D_6) δ 8.31 (d, 2H), 7.66 (d, 2H), 7.53 (t, 4H), 7.48 (d, 2H), 7.42-7.16 (m, 31H), 6.46 (d, 1H), 6.21 (app s, 1H), 6.15 (d, 1H, J=4.3 Hz), 5.81 (d, 1H, J=9.2 Hz), 5.72 (dt, 1H, J=12.8, 2.4 Hz), 5.40 (m, 1H), 5.38 (d,

1H, J=3.5 Hz), 5.20 (d, 1H, J=10.2 Hz), 5.12 (t, 2H), 5.00 (m, 3H), 4.84 (d, 1H, J-6.2 Hz), 4.81 (d, 1H, J=4.5 Hz), 4.73 (m, 2H), 4.70 (m, 2H), 4.67 (d, 1H, J=2.6 Hz), 4.65 (m, 1H), 4.59 (m, 3H), 4.53-4.46 (m, 6H), 4.40 (m, 5H), 4.36 (d, 1H, J=3.1 Hz), 4.30 (d, 1H, J=3.4 Hz), 4.26 (m, 3H), 4.23 (app s, 1H), 4.20 (m, 3H), 4.11 (m, 2H), 4.04 (d, 1H, J=5.9 Hz), 3.99 (s, 3H), 3.92 (d, 1H, J=3.2 Hz), 3.87 (d, 1H, J=2.9 Hz), 3.82 (d, 1H, J=6.5 Hz), 3.70 (m, 1H), 3.64 (s, 3H), 3.60 (d, 1H), 3.28 (t, 1H), 2.94 (dd, 1H, J=13.7, 4.5 Hz), 2.36 (t, 1H, J=13.3 Hz), 2.14 (s, 3H), 1.91 (s, 3H), 1.83 (s, 3H), 1.81 (s, 3H), 1.60 (s, 3H), 1.53 (d, 3H, J=6.5 Hz), 1.32-1.23 (m, 42H); ^{13}C NMR (100 MHz, $CHCl_3$) δ 170.43, 169.30, 169.20, 168.98, 168.03, 164.74, 155.82, 144.74, 139.09, 138.75, 138.52, 138.48, 138.40, 138.39, 138.25, 138.17, 132.56, 129.22, 128.85, 128.39, 128.35, 128.30, 128.25, 128.01, 127.79, 127.71, 127.60, 127.55, 127.50, 127.48, 127.34, 102.57, 102.24, 99.69, 99.11, 98.25, 81.35, 79.09, 87.22, 75.64, 75.40, 74.90, 74.60, 74.15, 73.95, 73.50, 73.33, 72.94, 72.84, 72.52, 71.37, 71.17, 70.47, 70.17, 69.66, 69.05, 68.47, 68.11, 67.96, 67.71, 67.55, 61.91, 61.54, 61.05, 57.70, 56.50, 53.65, 52.75, 31.94, 29.71, 21.70, 20.97, 20.89, 20.64, 20.46, 20.44, 17.57, 16.81, 15.38, 14.13, 11.89, 11.80; LRMS (FAB) $C_{125}H_{164}N_2O_{37}SSi_2Na$ 2373 $[M+Na]^+$.

3) Conjugation studies:

As described herein and as shown in Figure 6, the pentenyl group in FucGM1 was converted to an aldehyde group by ozonolysis and linked to -NH_2 groups of KLH by reductive amination method in the presence of sodium cyanoborohydride as described for globo H (see, Ragupathi G, Park TK, Zhang S, Kim IJ, Graeber L, Adluri S, Lloyd KO, Danishefsky SJ and Livingston PO. Immunization of mice with conjugates of fully synthetic hexasaccharide globo H results in antibody against human cancer cells: a combined chemical immunological approach to the fashioning of an anticancer vaccine. *Angewandte Chem. Int. Ed Engl. 36: 125-128. 1997.*). In the case of cross-linker method the aldehyde group obtained through ozonolysis was first reacted with hydrazide of MMCCH (4-(maleimidomethyl) cyclohexane-1-carboxyl hydrazide) and reacted with thiolated KLH as described in Ragupathi G, Koganty RR, Qiu D, Lloyd KO and Livingston PO. A novel and efficient method for synthetic carbohydrate conjugate vaccine preparation: Synthesis of sialyl Tn-KLH conjugate using a 4-(4-N-

maleimidomethyl) cyclohexane-1-carboxyl hydrazide (MMCCH) linker arm. *Glycoconjugate J.*, **15**: 217-221, 1998). For example, 4 mg of FucGM1 pentenyl glycoside in methanol was stirred at -78°C in a dry-ice/ethanol bath and ozone gas was passed through the solution for 10 min under vigorous stirring. The excess of ozone was then displaced with nitrogen over a period of 5 min. Methyl sulfide (100 µl) was added and the reaction mixture stirred at room temperature for 2 hours and distributed equally in two vials. The solvent was removed under a stream of nitrogen. The resulting white solid was used directly in the subsequent conjugation steps.

a) Direct Conjugation of FucGM1-aldehyde with KLH:

Two mg FucGM1-aldehyde was dissolved in 1 ml of 0.1M phosphate buffered saline (PBS) pH 7.2 and 4 mg of KLH in PBS. Two mg sodium cyanoborohydride was added and the mixture incubated under gentle agitation at 37°C for 48 h. After 16 h, an additional 1.0 mg sodium cyanoborohydride was added and the incubation continued. The unreacted FucGM1 aldehyde was removed completely with multiple washes using a Amicon Centriprep with molecular weight cut-off value 30000 dalton, with 6-7 changes of PBS at 4°C.

b) Conjugation of FucGM1-aldehyde through MMCCH to thiolated KLH:

Preparation of FucGM1-MMCCH

Two mg of FucGM1-aldehyde was dissolved in 1 ml of 0.1M sodium acetate buffer pH 5.5, and 4 mg of MMCCH in 100 µl of dimethyl sulfoxide (DMSO) was added. The reaction mixture was incubated at room temperature for 15 min with gentle stirring. At the end of 15 min 2 mg of solid sodium cyanoborohydride was added and the incubation continued at room temperature for 2 h. Unreacted MMCCH was removed in a Sephadex G10 column equilibrated previously with 0.1 M sodium phosphate buffer pH 6.0 containing 5 mM EDTA and eluted with the same buffer. The fractions positive for FucGM1 by TLC with orcinol were combined.

Addition of sulfhydryl groups to KLH

2-Iminothiolane (2 mg) dissolved in thiolation buffer (50 mM triethanolamine, 0.15 M NaCl, 5 mM EDTA, pH 8.0) was added to 4 mg of KLH and incubated with stirring at room temperature for 2 h. Unreacted 2-iminothiolane was removed by Sephadex G15 column equilibrated previously with 0.1 M sodium phosphate buffer pH 7.2 containing 5 mM EDTA and eluted with the same buffer. Fractions positive for KLH with BioRad protein assay dye reagent were combined. A small portion was used to estimate sulfhydryl groups in the thiolated KLH using Ellman's reagents and cysteine as standard as described earlier (Riddles PW, Blackeley RL, Zerner B Ellman's reagent: 5,5'-dithiobis(2-nitrobenzoic acid)--a reexamination, *Anal Biochem* **94**: 75-81, 1979.). The KLH was estimated by a dye method using BioRad dye reagent according to the manufacture's instructions.

Conjugation of FucGM1-MMCCH to thiolated KLH

The FucGM1-MMCCH product and thiolated KLH were mixed and adjusted to pH 7.2 with 0.1M sodium phosphate buffer pH 8.0. The reaction mixture was then incubated at room temperature overnight. The content of the FucGM1-MMCCH-KLH reaction vial was transferred to a Centriprep concentrator 30 (Amicon: molecular cut-off 30000 Dalton) and unreacted FucGM1-MMCCH was removed completely with multiple washes. The conjugate was checked by HPTLC for the absence of unreacted FucGM1 as mentioned above. The epitope ratios of two batches of conjugate were determined by estimating protein content by BioRad dye binding protein assay and carbohydrate by a HPAEC-PAD assay. The epitope ratio of FucGM1-KLH (by direct method) and FucGM1-MMCCH-KLH was 149/1 and 1527/1 respectively.

B. Example 2: Synthesis of Globo-H and conjugates thereof:

1) Discussion of Synthesis:

In yet another embodiment of the present invention, an improved synthesis of Globo-H is provided utilizing the novel synthetic methodology as presented herein. The previous synthesis of globo-H described by the present inventors (Park *et al. J. Am. Chem. Soc.* **1996**, *118*, 11488; Bilodeau *et al. J. Am. Chem. Soc.* **1995**, *117*, 7840; Kim *et al. J. Org. Chem.* **1995**, *60*, 7716) utilized all glycal building blocks (Danishefsky *et al.*

Angew. Chem. **1996**, *108*, 1482; *Angew. Chem. Int. Ed. Engl.* **1996**, *35*, 1380) for the rapid construction this complex oligosaccharide. These investigations relied on a highly convergent [3+3] coupling to generate the hexasaccharide core contained in the final target. In this approach, a flexible terminal glycal was maintained throughout the hexasaccharide construction. The glycal was then used to install the ceramide side chain present en route to globo-H glycolipid **16a** or its allyl glycoside **16b**. The synthesis of **16a** served to facilitate the proof of structure and immunocharacterization of globo-H. The allyl glycoside **16b** was employed for immunoconjugation to biocarrier proteins. The previous protocols were effective in producing *adequate* quantities of synthetic material for proof of structure, immunocharacterization, conjugation, mouse vaccinations and phase I human clinical trials. However, improved synthetic methodologies were desired to allow for efficient bioconjugation and also to provide suitable material for clinical purposes.

Difficulties associated with the allyl glycoside approach invited an alternative solution which, in general terms, is described herein, and is more specifically described for fucosyl GM1 above, and additionally for Globo-H below (Figure 7). Thus, it was conceived that a hexasaccharide could be constructed containing a glycoside that would enable linkage to carrier protein, already in place (see Figure 8). Indeed this group would already have been incorporated at the reducing end of the acceptor in the [3+3] coupling step. For successful implementation of this significant new variation of the globo-H synthesis (and other complex tumor associated antigens), it would be preferable that 1) the trisaccharide acceptor containing the glycoside construct would be readily synthesizable; 2) the glycoside construct would be compatible with the [3+3] coupling; 3) the construct, in contrast to the allyl glycoside, would survive global deprotection; and 4) efficient conjugation would be implementable.

An initial retrosynthetic analysis is shown in Figure 9. For maximum convergency, the ABC acceptor was envisioned containing the aforediscussed pentenyl glycosidic linker. Additionally, the same DEF trisaccharide donor sector would be utilized as described previously. The hexasaccharide core would then be assembled via a convergent [3+3] ABC+DEF coupling reaction using a sulfonamido glycosidation protocol (Griffith *et al. J. Am. Chem. Soc.* **1990**, *112*, 5811; Griffith *et al. J. Am. Chem.*

Soc. **1991**, *113*, 5863). Previous results had indicated that the presence of a free hydroxyl at C4 of the reducing end galactose (Figure 9, see asterisk) in the DEF donor would be necessary to direct the formation of the required β-linkage in the sulfonamido glycosidation (Park *et al. J. Am. Chem. Soc.* **1996**, *118*, 11488; Kwon *et al. J. Am. Chem. Soc.* **1998**, *120*, 1588). The sequencing of the [3+3] coupling was expected to take place as shown, owing to the higher reactivity of the equatorial C3 hydroxyl group (see bold) in the acceptor as compared to the necessary axial C4 hydroxyl group in the donor trisaccharide. Important to the strategy described herein is that, once the hexasaccharide is assembled, only protecting group manipulations would be required to reach the pro-vaccine antigen.

In general, the synthesis of the DEF trisaccharide sector is fairly concise, requiring six transformations starting from 6-*O*-TIPS galactal and tri-*O*-benzyl fluoro fucose (Park *et al. J. Am. Chem. Soc.* **1996**, *118*, 11488; Bilodeau *et al. J. Am. Chem. Soc.* **1995**, *117*, 7840; Kim *et al. J. Org. Chem.* **1995**, *60*, 7716). For purposes of a second-generation approach, the acceptor trisaccharide component can be dissected into a lactose derivative containing the desired NPG bearing a differentiated hydroxyl at C4' and an appropriate C-ring donor (Figure 9). The galactose donor monosaccharide also requires differential protection at C3, for eventual ABC+DEF coupling, and needs careful attention to efficiently allow for the required β-glycosidic linkage joining the AB+C domains.

As shown in Figure 10, the synthesis of the requisite ABC acceptor was conducted taking advantage of readily available lactose octaacetate, **17**. Conversion of **17** to the known α-bromo donor **18** (Reithal, Y. *J. Am. Chem. Soc.* **1952**, *74*, 4210; Dasgupet *et al. Carbohydr. Res.* **1994**, *264*, 155) was followed by silver carbonate mediated glycosylation with pentenyl alcohol as acceptor, to give **19** (Pent = $CH_2CH_2CH_2CH{=}CH_2$) in 75% yield on a 100 g scale (Rodriguez *et al. Aust. J. Chem.* **1990**, *43*, 665). Similar processing of **18** with silver triflate as promoter resulted in 17% yield of the desired product. Thus, with the formation of **19**, in an early stage of the synthesis, the linker was successfully installed to be used for late stage bioconjugation.

Subsequent steps were designed to generate a free acceptor site at C4' of **19** for an eventual AB + C coupling give the ABC trisaccharide (Figure 10). Removal of the ester

protecting groups in **19** to give a pentenyl lactoside was followed by a stannane mediated monobenzylation to selectively give the C3' benzyl ether (David *et al. J. Chem. Soc. Perkin Trans. I* **1981**, 1797; Maranduba *et al. Carbohydr. Res.* **1986**, *151*, 105). In a second step, the C4' and C6' hydroxyls were engaged as a benzylidene acetal to provide compound **20** as the only observable product (Jannson *et al. J. Org. Chem.* **1998**, *53*, 5629; Koeman *et al. Tetrahedron* **1993**, *49*, 5291; Qiu *et al. Liebigs Ann.* **1992**, 217). Finally, perbenzylation of the remaining hydroxyl groups in **20** and regioselective reductive cleavage of the benzylidene with sodium cyanoborohydride and anhydrous HCl gave the C4' alcohol **21** (Garegg, P.J. *Pure Appl. Chem.* **1984**, *56*, 845). Thus, starting from lactose octaacetate **17**, the AB pentenyl glycoside acceptor **21** was obtained in 7 steps and in 20% overall yield.

With large quantities of the protected pentenyl glycoside **21** available, attention was turned to the AB+C coupling to form the trisaccharide acceptor **24**. The previous synthesis of glycal **27** (Figure 10) required careful preparation of the highly activated β-fluoro donor **23** from glycal **22**. The C3 PMB ether contained in **22** was strategically incorporated to allow for eventual ABC+DEF coupling upon selective deprotection of this group. In the course of this work, it was discovered that α-**23** could be formed conveniently in high yield and on large scale. Accordingly, α-donor **23** was prepared from differentially protected glycal **22** by epoxidation, exposure to HF:pyridine to yield the *cis* fluoro-hydrin derivative and subsequent conversion of the resulting C2-hydroxyl to its benzyl ether. The anomeric α:β selectivity was demonstrated to be 10:1 and the overall yield in transforming **22** into **23** was 76%.

The effectiveness of the AB+C coupling using previously prepared β-**23** and the newly prepared α-**23** with the AB acceptor **21** was then investigated. The synthetic optimization of glycal trisaccharide **27** as a model case (see **23+26->27**) was also examined because of its presumed sensitivity to overly demanding coupling promoters. In these investigations it was discovered that the reduced reactivity of α-fluoro donors could be attenuated by conducting the couplings with highly fluorophilic promoters in judiciously chosen solvents, as summarized in Table 1. The previous coupling procedure using the predominantly β–fluoro donor **23** and glycal **26** to give glycal trisaccharide **27** employed Muykiyama coupling conditions (Mukaiyama *et al. Chem. Lett.* **1981**, 431;

Nicolaou *et al. J. Am. Chem. Soc.* **1990**, *112*, 3693; Nicolaou *et al. J. Chem. Soc. Chem. Commun.* **1991**, 870) and proceeded in 54% yield with modest anomeric selectivity (entry 1, Table 1). Investigations using other promoters with α-**23** are shown in entries 2 and 3, but produced little satisfaction in terms of overall efficiency. However, the preparation of glycal **27** was successfully extended to include the described α-donor **23** using strongly fluorophilic $Cp_2Zr(OTf)_2$ promotion (73% yield, entry 4). Gratifyingly, these optimized glycosidation conditions for formation of **27** were successfully applied to the AB+C coupling employing pentenyl glycoside **21** to provide trisaccharide **24** in yields that rivaled the parent reaction (80% yield, entry 6). Muykiyama coupling of β-**23** with **21** yielded 42% of trisaccharide **24** (entry 5). Satisfied with the events leading to smooth formation of large quantities of **24**, the [3+3] coupling would be investigated. The discharge of the lone PMB group in **24** could be effected in excellent yield (92%), thus completing the assembly of the desired ABC pentenyl acceptor **25**.

	Acceptor AB	Donor C	Promoter, Solvent	α : β selectivity	Yield, Product
1	**26**[a]	**23** (β)[a]	$SnCl_2$, $AgClO_4$, Et_2O	3:1	54% (α), 18% (β) **27**
2	**26**	**23** (10α:1β)	$Sn(OTf)_2$ Toluene:THF (5:1)	8:1	40% (α), 5% (β) **27**
3	**26**	**23** (10α:1β)	Cp_2ZrCl_2, $AgClO_4$, CH_2Cl_2:Et_2O	2.7:1	55% (α) **27**
4	**26**	**23** (10α:1β)	$Cp_2Zr(OTf)_2$, Toluene:THF (10:1)	10:1	72% (α), 8% (β) **27**
5	**21**	**23** (β)	$SnCl_2$, $AgClO_4$, Et_2O	3:1	42% (α) **24**
6	**21**	**23** (10α:1β)	$Cp_2Zr(OTf)_2$, Toluene:THF (5:1)	10:1	80% (α), 8% (β) 24

Table 1. Coupling conditions used to generate the ABC trisaccharide.
(a: see Park *et al. J. Am. Chem. Soc.* 1996, 118, 11488; Bilodeau *et al. J. Am. Chem. Soc.* **1995**, *117*, 7840; Kim *et al. J. Org. Chem.* **1995**, *60*, 7716).

The key step and final transformations completing the synthesis of **16c** are shown in Figure 11. Treatment of the known DEF donor **28** (see Figure 10) with MeOTf (Lönn, H. *Carbohydr. Res.* **1985**, *134*, 105; Lönn, H. *J. Carbohydr. Chem.* **1987**, *6*, 301) In the presence of acceptor **25** smoothly provided hexasaccharide **29** in 60% yield. The configuration of the new anomeric center of **29** was confirmed to be β-configured. The [3+3] coupling yield using trisaccharide acceptor **25** was comparable to the [3+3]

procedure using the glycal-based acceptor corresponding to **27**. The tremendous advantage of using **15**, however, is manifested in the steps which follow.

Global deprotection began with subjection of **29** to TBAF in order to remove the silyl ethers and the cyclic carbonate. The benzyl and sulfonamido protecting groups on the resulting penta-ol were then cleaved under the action of dissolving metal reduction. This protocol was followed by peracetylation to give the isolable hexasaccharide peracetate **30**. As in earlier steps, the pentenyl linkage proved highly reliable under the listed deprotection conditions. It is again notable by contrast that the corresponding allyl glycoside (to ultimately yield **16b**) is not stable to the reducing metal conditions required for global deprotection and therefore must be installed subsequent to deprotection. Deacetylation of **30** with methoxide yielded the fully deprotected pentenyl glycoside of globo-H, **16c**, notably poised for bioconjugation. *Importantly, in the second generation variation, progress toward **16d** from hexasaccharide construct **29** was greatly simplified because the need for additional functionalization to allow for conjugation is eliminated.*

Toward the goal of facilitating clinical evaluation of synthetic globo-H, **16c** has been conjugated to carrier protein KLH for purposes of creating a functional vaccine. The first step of this procedure involved ozonolysis of the pendant olefin, followed by reductive work-up, to give the uncharacterized aldehyde intermediate **31**, as shown in Figure 12. Reductive amination with KLH and sodium cyanoborohydride in phosphate buffer yielded vaccine glycoconjugate **16d** (n = 3). Covalent attachment of the carbohydrate to the proteins presumably occurs through the ε-amino groups on exposed lysine residues in KLH. Hydrolytic carbohydrate analysis of **16d** revealed approximately 350 carbohydrate residues per molecule of carrier protein.

*2) **Experimentals:***

Peracetyl pentenyl-β-D-lactoside (19). To a cooled (ice bath) suspension of lactose octaacetate (100.0 g, 147.7 mmol), glacial acetic acid (30 mL) and acetic anhydride (30 mL) was added 100 mL of 30% HBr in AcOH dropwise over a period of 60 minutes. The reaction mixture stirred for 1 hour and the ice bath was removed. Upon stirring for an additional 2 hours at room temperature, the mixture became a homogeneous yellow solution. The solution was diluted with H_2O (1000 mL) and

extracted with $CHCl_3$ (3x400 mL). The organic extracts were washed with H_2O (2x1000 mL), satd. $NaHCO_3$ (3x500 mL), dried over $MgSO_4$ and concentrated. The product was azeotroped with anhydrous benzene and dried under high vacuum to yield 98.8 g (96%) of the lactosyl bromide which was used without further purification.

To a suspension of Ag_2CO_3 (100 g, 362.6 mmol), freshly activated molecular sieves (15 g) and a crystal of I_2 in 400 mL CH_2Cl_2 was added pentenyl alcohol (5.0 equiv., 73.4 mL) and then the lactosyl bromide (98.8 g, 141.4 mmol) in 400 mL of CH_2Cl_2. After stirring in the dark at room temperature for 16 hours, the reaction was filtered through a plug of Celite with additional CH_2Cl_2 and concentrated to a yellow oil which was purified by flash column chromatography (10% EtOAc/hexanes→50% EtOAc/hexanes) to yield 74.7 g (75%) of the pentenyl lactoside as a white foam. $[\alpha]_{22}^{D}$ -48.9° (*c* 7.5, $CHCl_3$); IR (film $CHCl_3$) 2941, 1751, 1369, 1224, 1054 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.60 (m, 1H), 5.17 (d, 1H, J=2.7 Hz), 5.02 (m, 1H), 4.93 (dd, 1H, J=7.9, 10.3 Hz), 4.85 (d, 1H, J=1.6 Hz), 4.78 (m, 2H), 4.71 (dd, 1H, J=9.6, 7.9 Hz), 4.30 (m, 3H), 3.93 (m, 3H), 3.66 (m, 3H), 3.45 (m, 1H), 3.30 (m, 1H), 1.98 (s, 3H), 1.94 (s, 3H), 1.91 (m, 2H), 1.89 (s, 3H), 1.88 (s, 6H, 2xCH3), 1.87 (s, 3H), 1.79 (s, 3H), 1.49 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.33, 170.28, 170.09, 170.00, 169.74, 69.54, 169.01, 137.72, 115.00, 101.01, 100.51, 76.27, 72.76, 72.48, 71.64, 70.94, 70.58, 69.23, 69.01, 66.52, 61.97, 60.73, 29.75, 28.49, 20.80, 20.75, 20.64, 20.57, 20.45. FAB-HRMS calc'd for $C_{31}H_{44}O_{18}Na^+$; 727.2425. Found; 727.2418.

Pent-4-enyl 3'-*O*-benzyl-4', 6'-*O*-benzylidenyl-β-D-lactoside (20). Peracetylated pentenyl lactoside, **8**, (18.2 g, 25.8 mmol) was dissolved in 300 mL of anhydrous MeOH and 2.0 mL of NaOMe (25% in MeOH) was added. The reaction stirred at rt for 16 hours and was neutralized with Dowex-H^+ (pH 5-6). The reaction was filtered with additional MeOH and concentrated to a white solid, **19a**, (10.6 g, quantitative) which was used without further purification: ^1H NMR (D_2O, 400 MHz) δ 5.81 (m, 1H), 5.00 (dd, 1H, J=17.3, 1.9 Hz), 4.92 (dd, 1H, J=8.9 Hz), 4.74 (m, 1H), 4.39 (d, 1H, J=8.0 Hz), 4.35 (d, 1H, J=7.8 Hz), 3.72-3.42 (m, 12H), 3.21 (m, 1H0, 2.06 (m, 2H), 1.63 (m, 2H); ^{13}C NMR (D_2O, 100 MHz) δ 141.27, 117.31, 105.42, 104.54, 80.85, 77.84, 77.24, 76.92, 75.33, 75.00, 73.44, 72.47, 71.03, 63.52, 62.56, 31.83, 30.48.

The hepta-ol **19a** (1.14 g, 2.8 mmol) and dibutyltin oxide (0.76 g, 3.1 mmol) were heated at reflux in benzene (70 mL) with azeotropic water removal for 15 h. The mixture was doubled in concentration, cooled to room temperature, and benzyl bromide (0.69 ml, 5.8 mmol) and Bu_4NI (1.03 g, 2.8 mmol) were added. The mixture was heated at reflux 3.5 h, cooled, silica gel was added to the flask, and the solvent was evaporated. The residue was applied to a column of silica gel, tin by-products were removed by flushing with hexanes, and elution (5 % MeOH in CH_2Cl_2) gave the pure 3'-O-benzyl ether (0.76 g, 54 %) as a white foam: $[\alpha]_{22}^{D}$ +36.7° (*c* 2.73, $CHCl_3$); IR (film $CHCl_3$) 3371, 2924, 2880, 1372, 1157, 1074 cm^{-1}; ^1H NMR (MeOH-d_4, 400 MHz) δ 7.46-7.40 (m, 2H), 7.35-7.20 (m, 3H), 5.92-5.72 (m, 1H), 5.08-4.93 (m, 2H), 4.76 (d, 1H, J=11.8 Hz), 4.65 (d, 1H, J=11.8 Hz), 4.38 (d, 1H, J=7.8 Hz), 4.28 (d, 1H, J=7.8 Hz), 4.02 (d, 1H, J=2.9 Hz), 3.95-3.63 (m, 6H), 3.61-3.48 (m, 4H), 3.43-3.20 (m, 3H), 2.20-2.10 (m, 2H), 1.78-1.65 (m, 2H); ^{13}C NMR (MeOH-d_4, 100 MHz) δ 139.77, 139.47, 129.29, 129.08, 128.64, 115.19, 105.02, 104.23, 82.17, 80.74, 76.88, 76.40, 76.35, 74.71, 72.55, 71.81, 70.23, 67.02, 62.44, 61.91, 31.22, 30.07. FAB-HRMS calc'd for $C_{24}H_{36}O_{11}Na^+$; 523.2155. Found; 523.2137.

The 3'-O-benzyl ether (0.6 g, 1.20 mmol) was dissolved in acetonitrile and DMF (5:2, 7 mL), and benzaldehyde dimethylacetal (0.47 mL, 3.1 mmol) and CSA (14 mg, 60 μmol) were added. After stirring 16 h at room temperature, the mixture was diluted with CH_2Cl_2 and washed with sat. $NaHCO_3$. The organic extracts were dried ($MgSO_4$), evaporated, and following addition of ether (100 mL) to the resulting residue, the pure **20** was recovered by filtration (0.51 g, 72 %): $[\alpha]_{22}^{D}$ +111° (*c* 2.21, MeOH); IR ($CHCl_3$ film) 3440, 2872, 1368, 1163, 1109, 1048, 1005 cm^{-1}; ^1H NMR (MeOH-d_4, 400 MHz) δ 7.55-7.11 (m, 10H), 5.82-5.69 (m, 1H), 5.45 (s, 1H), 4.98-4.83 (m, 2H), 4.64 (d, 2H, J=3.0 Hz), 4.40 (d, 1H, J=7.9 Hz), 4.23 (d, 1H, J=3.4 Hz), 4.18 (d, 1H, J=7.8 Hz), 4.15-3.98 (m, 2H), 3.87-3.66 (m, 4H), 3.55-3.10 (m, 7H), 2.20-2.10 (m, 2H), 1.65-1.53 (m, 2H); ^{13}C NMR (MeOH-d_4, 100 MHz) δ 139.76, 139.49, 139.47, 129.86, 129.30, 129.07, 129.03, 128.72, 127.35, 115.19, 104.69, 104.28, 102.03, 80.63, 80.17, 76.37, 76.28, 74.77, 74.73, 72.84, 70.86, 70.25, 68.17, 61.70, 31.22, 30.07. FAB-HRMS calc'd for $C_{31}H_{40}O_{11}Na^+$; 611.2468. Found; 611.2465.

Pent-4-enyl 2, 2', 3, 3', 6, 6'-hexa-*O*-benzyl-β-D-lactoside (21). The tetraol **20** (0.51 g, 0.87 mmol) and Et_4NI (0.12 g, 0.43 mmol) were dried (azeotropic distillation with benzene), dissolved in DMF (5 mL) and cooled to 0°C. Benzyl bromide (0.83 mL, 7.0 mmol) was added followed by NaH (0.22 g, 60 %, 5.6 mmol) and the mixture was allowed to warm to room temperature over 14 h. The mixture was diluted with ethyl acetate, washed with water, the organic layer was dried ($MgSO_4$) and evaporated. Purifiction of the residue by chromatography on silica gel (4:1→2:1 hexanes:ethyl acetate) gave pure pentabenzyl lactoside as a white foam (0.80 g, 97 %): $[\alpha]_{22}^{D}$ +129° (*c* 1.63, $CHCl_3$); IR ($CHCl_3$ film) 3030, 2866, 1453, 1365, 1096, 1063, 1028, 911 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.50-7.05 (m, 30H), 5.80-5.65 (m, 1H), 5.38 (s, 1H), 5.10 (d, 1H, J=10.6 Hz), 4.99-4.60 (m, 9H), 4.47 (d, 1H, J=12.1 Hz), 4.38 (d, 1H, J=7.8 Hz), 4.30 (d, 1H, J=7.8 Hz), 4.25 (d, 1H, J=12.1 Hz), 4.12 (d, 1H, J=13 Hz), 3.94 (d, 1H, J=3.4 Hz), 3.92-3.60 (m, 6H), 3.54 (dd, 1H, J=8.8 Hz, 9.2 Hz), 3.46 (dd, 1H, J=2.6 Hz, 7.0 Hz), 3.40-3.23 (m, 3H), 2.85 (s, 1H), 2.22-2.00 (m, 2H), 1.75-1.60 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 138.92, 138.63, 138.51, 138.04, 128.80, 128.52, 128.31, 128.24, 128.17, 128.13, 128.06, 128.03, 128.00, 127.69, 127.65, 127.54, 127.49, 127.38, 127.30, 126.52, 114.84, 103.59, 102.83, 101.30, 83.01, 81.81, 79.60, 78.76, 77.65, 75.73, 75.22, 75.05, 74.97, 73.61, 72.91, 71.56, 69.27, 68.90, 68.27, 66.28, 30.18, 28.89. FAB-HRMS calc'd for $C_{59}H_{64}O_{11}Na^+$; 971.4346. Found; 971.4375.

The benzylidene (0.63 g, 0.66 mmol) was dissolved in THF (6.6 mL) and stirred with freshly activated 4ÅMS (0.25 g) 10 min at room temperature. In one portion $NaCNBH_3$ (0.21 g, 3.3 mmol) was added followed by anhydrous HCl (2.0 M Et_2O), dropwise until the mixture no longer bubbled (approx. 2 mL). After stirring and additional 10 min, the mixture was passed through a plug of Celite washing with ethyl acetate, the filtrate was washed with sat. $NaHCO_3$ and brine, dried ($MgSO_4$) and the organic layers evaporated. Purification by column chromatography (9:1 hexanes:ethyl acetate) gave pure **21** as white solid (0.49 g, 79 %): $[\alpha]_{22}^{D}$ +200° (*c* 1.05, $CHCl_3$); IR ($CHCl_3$ film) 3474, 3062, 3029, 2869, 1453, 1364, 1094, 1028 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.40-7.06 (m, 30H), 5.80-5.66 (m, 1H), 5.02-4.85 (m, 3H), 4.81 (d, 1H, J=11.0 Hz), 4.75-4.54 (m, 6H), 4.67 (d, 1H, J=12.2 Hz), 4.42-4.26 (m, 5H), 3.94 (s, 1H), 3.92-3.81 (m, 2H), 3.71 (dd, 1H, J=10.7 Hz, 4.1 Hz), 3.64 (d, 1H, J=10.6 Hz), 3.57 (dd, 1H, J=9.4 Hz, 5.5 Hz), 3.55-3.42

(m, 3H), 3.38 (dd, 1H, J=5.2 Hz, 9.6 Hz), 3.36-3.21 (m, 4H), 2.32 (s, 1H), 2.15-2.02 (m, 2H), 1.74-1.60 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 139.04, 138.54, 138.52, 138.23, 138.09, 137.96, 137.81, 128.33, 128.15, 127.93, 127.66, 127.50, 114.80, 103.50, 102.43, 82.79, 81.68, 80.99, 79.27, 76.52, 75.22, 75.10, 74.99, 74.83, 73.37, 72.99, 72.67, 71.86, 69.10, 68.32, 68.16, 66.00, 30.11, 28.83. FAB-HRMS calc'd for $C_{59}H_{66}O_{11}Na^+$; 973.4503. Found; 973.4513.

α-Fluoro donor (23). A solution of 3-*O*-PMB-4,6-Di-*O*-benzyl-galactal (2.24 g, 5.02 mmol) in dry CH_2Cl_2 (5 ml) under N_2 at 0°C was treated with dimethyldioxirane (0.11 M, 47 ml), and the mixture was stirred until all of the glycal was consumed (~ 1h, TLC 30% EtOAc in hexane) Note: *Elevated temperature and/or excess of DMDO will prompt oxidation of the PMB group and lower reaction yield.* The solvents were evaporated under vacuum at 0°C and the residue was kept under high vacuum. The flask containing galactal epoxide was charged with freshly prepared 4 A molecular sieves (2 g), dry THF (50 ml) and cooled to 0°C. HF/Pyr complex (0.79 ml, ~5 equiv.) was added dropwise via syringe. The reaction mixture was left overnight to slowly reach room temperature and quenched with Et_3N (1.27 g, ~ 2.5 equiv.) to reach pH ~ 7. The mixture was filtered through a pad of anhydrous $MgSO_4$ and rinsed three times with 50 ml of EtOAc. The filtrate was washed with water (50 ml) and saturated $NaHCO_3$ solution (50 ml), dried over $MgSO_4$ and concentrated to dryness. Flash column chromatography (EtOAc/hexanes, 2/1) gave 2.06 g (85% yield) of fluorohydrin as a mixture of anomers α:β = 10 : 1. ^{19}F NMR ($CDCl_3$, 376 MHz, C_6F_6 as external standard) δ 9.7 (dd, α, J = 54.4, 25.0 Hz) 20.0 (dd, β, J = 53.9, 13.1 Hz); ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.38 – 7.24 (m, 12H), 6.90 (d, 2H, J = 8.7 Hz), 5.70 (dd, 1H, J = 54.4, 2.8 Hz), 4.89 and 4.57 (two d, 2H, J = 11.3 Hz), 4.70 and 4.54 (AB q, 2H, J = 11.2 Hz), 4.54 and 4.46 (AB q, 2H, J = 11.8 Hz), 4.17 (AMX octet, 1H, J = 2.8, 10.1, 25.0 Hz), 4.13 (br t, 1H, J = 6.8 Hz), 4.06 (d, 1H, J = 1.5 Hz), 3.81 (s, 3H), 3.74 (dd, 1H, J = 2.6, 10.1 Hz), 3.60 (m, 2H).

The above mixture (8.29 g, 17.2 mmol) was dissolved in dry DMF (100 ml) containing freshly prepared 4 A molecular sieves (3 g) under N_2 at 0°C, treated with benzyl bromide (4.41 g, 25.8 mmol, 1.5 equiv.) and finally with NaH (1.24 g, 60% dispersion in oil, 30.86 mmol, 1.8 equiv.), and stirred overnight at room temperature. The reaction was quenched with glacial acetic acid (0.93 g, 0.9 equiv.) and the mixture filtered through a

pad of anhydrous $MgSO_4$ with EtOAc (4x50 ml). The organic solution was washed with water (4 x 50 ml), dried ($MgSO_4$) and concentrated *in vacuo.* Flash column chromatography of the residue (hexane/EtOAc, 4/1) gave 9.36 g (95%) of the title compound as colorless liquid with the same ratio of anomers $\alpha : \beta = 10 : 1$ as the starting fluorohydrin. ^{19}F NMR ($CDCl_3$, 376 MHz, C_6F_6 as external standard) δ 11.5 (dd, α, J = 53.7, 25.2 Hz), 22.8 (dd, β, J = 53.4, 13.0 Hz). For analytical purpose 50 mg of pure α anomer was obtained using preparative HPLC. $[\alpha]_{22}^{D}$ - 54.5° (*c* 0.55, $CHCl_3$); ^1H NMR ($CDCl_3$, 500 MHz), δ 7.38–7.24 (m, 17H), 6.88 (d, 2H, J=8.6 Hz), 5.58 (dd, 1H, J=53.7, 2.7 Hz), 4.93 (d, 2H, J=11.34 Hz), 4.56 (d, 2H, J=11.34 Hz), 4.85 (AB q, 2H, J = 11.78 Hz), 4.72 (AB q, 2H, J = 11.78 Hz), 4.73 (AB q, 2H, J = 11.3 Hz), 4.68 (AB q, 2H, J = 11.3 Hz), 4.47 (AB q, 2H, J = 11.84 Hz), 4.41 (AB q, 2H, J = 11.84 Hz), 4.09 (br t, 1H, J = 6.5 Hz), 4.02 (AMX m, 1H, J = 2.7, 10.05, 25.2 Hz), 3.98 (app s, 1H), 3.92 (dd, 1H, J = 2.64, 10.05 Hz), 3.81 (s, 3H), 3.54 and 3.52 (ABX m, 2H, J=9.3, 6.05, 7.0 Hz); ^{13}C NMR ($CDCl_3$, 125MHz) δ 159.20, 138.35, 138.08, 137.71, 130.43, 129.18, 128.39, 128.25, 128.14, 127.92, 127.8, 127.78, 127.66, 113.81, 106.25 (d, J = 229.0 Hz), 78.09, 75.65 (d, J = 23.5 Hz), 74.79 ($ArCH_2$), 74.29, 73.70 ($ArCH_2$), 73.45 ($ArCH_2$), 72.71 ($ArCH_2$), 71.70 (d, J = 2.7 Hz) 68.26, 55.24 (CH_3O); MS (NH_3) 586 ($[M + NH_4]^+$).

PMB trisaccharide (24). A mixture of lactoside (**21**) (402 mg, 0.423 mmol) and fluoro donor (**23**) (485 mg, 0.846 mmol, 2 equiv.) was azeotroped with anhydrous benzene (3x10 ml) and further dried on high vacuum for 3 h. The above mixture was dissolved in toluene (3.8 ml) and transferred via cannula to a flask containing freshly prepared 4 Å molecular sieves (0.68 g) under N_2, treated with 2,6-di-tert-butylpyridine (143 μl) and cooled to -20 °C. $(Cp)_2Zr(OTf)_2$ (225 mg, 0.381 mmol, 0.9 equiv.) was suspended in THF (0.38 ml) and added via a cannula to the reaction mixture. The reaction was stirred for 72 h at 7 °C in darkness. The reaction mixture was diluted with EtOAc (10 ml) and filtered through a pad of anhydrous $MgSO_4$ with EtOAc (3x 10mL). The filtrate was washed with satd. $NaHCO_3$ solution (2 x 10 ml), dried over $MgSO_4$, and concentrated to dryness. Flash column chromatography (2% Et_2O/CH_2Cl_2) gave 509 mg (80%) of desired α-product (**24**) and 51 mg (8%) of β-product. $[\alpha]_{22}^{D}$ +24.6° (*c* 3.90, $CHCl_3$); IR ($CHCl_3$ film) 3062, 3029, 2919, 2868, 1612, 1513, 1496, 1364, 1303, 1248,

$1028\ cm^{-1}$; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.40-6.95 (m, 49 H), 6.69 (d, 1H, J=8.5 Hz), 5.73 (m, 1H), 5.00-4.93 (m, 2H), 4.92-4.84 (m, 2H), 4.82-4.73 (m, 2H), 4.72-4.63 (m, 5H), 4.61 (d, 1H, J=13.0 Hz), 4.48-4.35 (m, 5H), 4.34-4.24 (m, 4H), 4.16 (d, 2H, J=6.8 Hz), 4.07 (dd, 1H, J=8.8 Hz), 4.02-3.80 (m, 8H), 3.78-3.60 (m, 3H), 3.68 (s, 3H), 3.60-3.35 (m, 6H), 3.35-3.18 (m, 4H), 3.12-3.04 (m, 1H), 2.06 (m, 2H), 1.65 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 158.76, 139.66, 139.45, 139.26, 139.16, 139.09, 138.92, 138.57, 138.52, 131.39, 129.30, 128.95, 128.70, 128.60, 129.30, 128.08, 127.95, 115.35, 114.02, 104.05, 103.35, 101.25, 83.14, 82.17, 79.91, 79.71, 77.77, 77.04, 75.69, 75.58, 75.46, 75.33, 74.17, 73.75, 73.54, 73.48, 72.65, 72.54, 69.91, 69.71, 68.80, 68.33, 68.19, 55.11, 30.14, 28.86; FAB-HRMS calc'd for $C_{94}H_{102}O_{17}Na^+$; 1525.7014. Found; 1525.6996.

Trisaccharide acceptor (25). A solution of PMB trisaccharide (**24**) (445 mg, 0.296 mmol) in methylene chloride (10 ml) at 0 °C was treated with phosphate buffer (1.5 ml, pH = 7.4) and DDQ (89 mg, 1.3 equiv.) and stirred at 0 °C for 5 h. The reaction mixture was diluted with EtOAc (50 ml), washed with satd. $NaHCO_3$ solution (2 x 20 ml) and water (20 ml), dried over $MgSO_4$, and concentrated to dryness. The crude material was purified by flash column chromatography (4% ether in methylene chloride) to give 344 mg (84%) of deprotected trisaccharide (**25**) as a colorless oil. $[\alpha]_{22}^{D}$ +28.2° (*c* 5.70, $CHCl_3$); IR ($CHCl_3$ film) 3570, 3062, 3029, 2913, 2868, 1496, 1453, 1364, 1208, 1095 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.77-7.06 (m, 45H), 5.73 (m, 1H), 5.01 (dd, 1H, J=5.5, 3.3 Hz), 4.95 (dd, 1H, J=5.8, 2.6 Hz), 4.90 (m, 1H), 4.78 (d, 1H, J=10.9 Hz), 4.75 (d, 1H, J=11.4 Hz), 4.70-4.59 (6d, 6H), 4.47-4.37 (m, 5H), 4.28 (m, 3H), 4.19 (s, 2H), 4.08-3.91 (m, 6H), 3.85 (m, 2H), 3.69 (m, 5H), 3.66 (1H, d, J=11.0 Hz), 3.50-3.19 (m, 9H), 3.10 (dd, 1H), 2.07 (m, 2H), 1.79 (d, 1H, OH), 1.65 (d, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 139.36, 138.72, 138.63, 138.52, 138.41, 138.29, 138.19, 138.07, 137.98, 128.35, 128.20, 128.06, 127.97, 127.66, 127.54, 127.08, 114.82, 103.55, 102.67, 99.58, 82.93, 81.67, 81.55, 79.32, 77.61, 76.90, 75.13, 75.02, 74.96, 74.80, 73.08, 72.99, 72.91, 72.01, 69.95, 69.22, 69.15, 68.34, 67.73, 67.57, 60.35, 30.19, 28.92; FAB-HRMS calc'd for $C_{86}H_{94}O_{16}Na^+$; 1405.6439. Found; 1405.6385.

Hexasaccharide (29). The thioethyl donor **28** (543 mg, 0.425 mmol) and acceptor **25** (587 mg, 0.425 mmol) were combined, azeotroped with anhydrous benzene (5x5 mL)

and placed under high vacuum for 5 hours. The mixture was then dissolved in 3.5 mL CH_2Cl_2 and 7.0 mL Et_2O, treated with freshly prepared molecular sieves and cooled to 0 °C. Methyl triflate (3.0 equiv., 144 μL) was added in one portion and the reaction stirred at 0 °C for 3 hours. Another 144 μL of MeOTf was added and the reaction was allowed to stir for an additional 2 hours at 5 °C. The reaction was quenched by the addition of solid $NaHCO_3$, filtered through Celite with EtOAc, concentrated and purified by HPLC (17% EtOAc/hexanes) to give 663 mg (60%) of hexasaccharide as a white foam. $[\alpha]_{22}{}^{D}$ – 9.7° (*c* 1.00, $CHCl_3$); IR ($CHCl_3$ film) 3533, 3343, 3087, 3030, 2940, 2865, 1790, 1496, 1453, 133, 1095 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.76 (d, 2H, J=7.5 Hz), 7.45-7.00 (m, 63H), 5.84 (m, 1H), 5.20 (s, 1H), 5.11 (d, 1H, J=3.2 Hz), 5.09 (d, 1H, J=3.6 Hz), 5.05 (d, 1H, J=3.3 Hz), 5.03 (m, 1H), 4.92 (m, 2H), 4.86 (d, 1H, J=6.0 Hz), 4.82 (m, 2H), 4.78 (1H, d, J=2.2 Hz), 4.74-4.61 (m, 8H), 4.53-4.44 (4d, 4H), 4.38-4.30 (m, 4H), 4.18-3.82 (m, 20H), 3.76-3.66 (m, 5H), 3.66-3.60 (m, 2H), 3.58-3.52 (m, 2H), 3.48-3.40 (m, 2H), 3.38-3.32 (m, 2H), 3.29-3.25 (m, 3H), 3.06 (dd, 1H, J=10.2 Hz), 2.86 (s, 1H), 2.74 (m, 1H), 2.16 (m, 2H), 1.74 (m, 2H), 1.23 (s, 3H, J=6.5 Hz), 1.16-1.07 (m, 42H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 155.49, 140.71, 139.37, 138.96, 138.72, 137.70, 138.66, 138.55, 138.42, 138.37, 138.10, 138.07, 138.04, 137.88, 132.07, 128.89, 128.64, 128.50, 128.27, 128.16, 128.04, 127.86, 127.68, 127.53, 127.34, 127.20, 114.79, 103.49, 103.14, 102.61, 99.63, 99.12, 97.79, 82.26, 81.61, 81.34, 80.45, 79.36, 78.95, 78.26, 77.82, 77.64, 77.45, 77.24, 77.16, 76.83, 76.45, 75.39, 75.28, 75.12, 74.98, 74.89, 74.78, 73.94, 73.13, 72.94, 72.92, 72.52, 71.91, 71.81, 71.25, 71.11, 69.35, 69.23, 69.18, 68.18, 68.11, 68.01, 67.77, 67.54, 61.98, 61.72, 56.03, 30.16, 28.88, 18.01, 18.00, 17.95, 17.92, 11.85, 11.82; LRMS (FAB) calc'd for $C_{150}H_{185}NO_{32}SSi_2Na^+$ 2624.

Peracetate of globo-H pentenyl glycoside (30). To a solution of the hexasaccharide (585 mg, 0.224 mmol) in THF (10 mL) was added TBAF (1.0 M THF, 10 equiv., 2.24 mL). The reaction stirred at rt for 3 days, poured into ice water and extracted with EtOAc (3x50 mL). The organic extracts were washed with satd. $NaHCO_3$ (50 mL) and brine (50 mL), dried over $MgSO_4$ and concentrated to an oil which was purified through a short plug of silica gel with EtOAc. The resulting triol was dissolved in anhydrous MeOH (8 mL) and sodium methoxide was added (0.25 mL of a 25% solution in MeOH).

The reaction stirred at rt for 18 hours, neutralized with Dowex-H^+, filtered with MeOH washings and concentrated. To the resulting white solid was added THF (2.0 mL) and condensed liquid NH_3 (~25 mL) at -78 °C. Sodium (~500 mg) was added and the resulting blue solution stirred at -78 °C for 2 hours. The reaction was quenched with anhydrous MeOH (~10 mL), brought to rt and concentrated under a stream of dry N_2 to a volume of ~5 mL. The reaction was neutralized with Dowex-H^+, filtered with MeOH washing and concentrated to a white solid. The white solid was dissolved in 5.0 mL pyridine and 5.0 mL CH_2Cl_2 and cooled to 0 °C. A crystal of DMAP was added followed by acetic anhydride (5.0 mL). The ice bath was removed and the reaction stirred at rt overnight. Concentration followed by purification by flash column chromatography (gradient elution 75% EtOAc/hexanes→100% EtOAc→5% MeOH/EtOAc) gave 168 mg (42%) of **30** as a white solid: $[\alpha]_{22}^{D}$ 4.37° (*c* 1.85, $CHCl_3$); IR ($CHCl_3$ film) 2939, 1747, 1370, 1229, 1066 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 7.66 (d, 1H, J=6.5 Hz), 5.77 (m, 1H), 5.58 (d, 1H, J=3.2 Hz), 5.47 (d, 1H, J=3.5 Hz), 5.39 (d, 1H, J=3.2 Hz), 5.29 (dd, 1H, J=10.9, 3.0 Hz), 5.24-5.06 (m, 5H), 5.04-5.02 (m, 1H), 4.99-4.85 (m, 4H), 4.74 (dd, 1H, J=10.9, 2.9 Hz), 4.53-4.40 (m, 5H), 4.36 (m, 1H), 4.26 (dd, 1H, J=10.6, 3.4 Hz), 4.18-4.03 (m, 6H), 3.99-3.96 (m, 2H), 3.87-3.81 (m, 3H), 3.77-3.74 (m, 1H), 3.51-3.45 (m, 1H), 3.03 (m, 1H), 2.16 (s, 3H), 2.15 (s, 3x3H), 2.13-2.11 (m, 2H), 2.10 (s, 3H), 2.09 (s, 3H), 2.08 (s, 2x3H), 2.08 (s, 3H), 2.07 (s, 3H), 2.05 (s, 3H), 2.04 (s, 2x3H), 2.00 (s, 3H), 1.97 (s, 2x3H), 1.89 (s, 3H), 1.65 (m, 2H), 1.62 (s, 3H), 1.14 (d, 3H, J=6.5 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 172.31, 171.55, 170.78, 170.61, 170.57, 170.48, 170.41, 170.30, 170.08, 169.75, 169.61, 169.57, 169.44, 168.96, 137.76, 115.07, 102.05, 101.29, 100.45, 99.23, 98.74, 94.29, 77.24, 77.16, 76.07, 73.68, 73.40, 73.17, 72.63, 72.34, 71.85, 71.77, 71.56, 71.34, 70.83, 70.71, 70.19, 70.08, 69.32, 69.03, 68.88, 68.09, 68.01, 67.59, 67.32, 64.48, 29.80, 28.54, 23.12, 20.90, 20.88, 20.82, 20.74, 20.73, 20.72, 20.71, 20.64, 20.62, 20.55, 20.54, 20.49, 15.91; FAB-HRMS calc'd for $C_{77}H_{107}NO_{47}Na^+$;1820.5911. Found; 1820.5994.

Globo-H, pentenyl glycoside (16c). The peracetate (20 mg, 0.011 mmol) was dissolved in anhydrous MeOH (2.0 mL) and 100 μL of sodium methoxide was added (25% solution in MeOH). The reaction stirred at rt for 18 hours, was neutralized with

Dowex-H^+ (~pH 6-7), filtered with MeOH washings, concentrated and purificated using RP silica gel ($H_2O \rightarrow 1\%$ MeOH/H_2O) then P-2 Gel (H_2O elutent) to yield 12 mg (99%) of a white solid. $[\alpha]_{22}^{D}$ 3.00° (*c* 1.00, MeOH); IR 3374, 2930, 1641, 1372, 1070 cm^{-1}; ^1H NMR (MeOH, 400 MHz) δ 5.79 (m, 1H), 5.18 (d, 1H, J=3.9 Hz), 4.98 (dm, 1H, J=7.2 Hz), 4.91 (m, 1H), 4.87 (m, 1H), 4.51 (s, 1H), 4.49 (d, 1H, J=1.4 Hz), 4.41-4.36 (m, 2H), 4.24-4.20 (m, 4H), 4.10 (d, 1H, J=2.5 Hz), 4.06-4.00 (m, 3H), 3.94 (s, 1H), 3.87-3.45 (m, 22H), 3.35-3.31 (m, 2H), 3.19 (t, 1H, J=8.8 Hz), 2.10 (m, 2H), 1.96 (s, 3H), 1.66 (m, 2H), 1.19 (d, 3H, J=6.5 Hz); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 174.53, 139.53, 115.27, 105.50, 105.44, 104.30, 103.96, 102.81, 101.07, 81.29, 80.59, 80.04, 79.16, 78.00, 76.81, 76.57, 76.49, 76.45, 76.39, 75.57, 74.89, 74.69, 73.58, 72.64, 72.49, 71.56, 70.65, 70.63, 70.38, 70.31, 69.70, 68.13, 62.63, 62.59, 61.94, 61.62, 53.11, 49.90, 31.29, 30.14, 23.55, 16.76. FAB-HRMS calc'd for $C_{43}H_{73}NO_{30}Na^+$; 1106.4115. Found; 1106.4105.

C. Example 3: Preparation of glycoamino acids and inventive glycopeptides:

1) Discussion of synthetic methods:

In general, it was desired to incorporate the two antigens described above, fucosyl GM1 and globo-H into glycopeptides. As shown in Figure 13, a tranformation utilizing catalytic asymmetric hydrogenation of glycosylated amide esters was contemplated. The new approach anticipated a Horner-Emmons olefination of the protected aldehyde with a suitably protected glycine derived phosphonate to give an enamide ester. Subsequent catalytic asymmetric hydrogenation would hopefully yield diastereromerically pure glycoamino acid.

In but one example, an inventive glycoamino acid, based on a peraceylated lactose derivatives was prepared. Specifically the required lactose derived enamide ester substrate was prepared. The required lactose derived enamide ester substrate was prepared according to Figure 14. Ozonolysis of the NPG **32** (Allen *et al., Chem. Eur. J.* **2000,** *6*, 1366) followed by reductive work-up gave the corresponding aldehyde derivative. The crude aldehyde was then subjected to Horner-Emmons olefination using tetramethylguanidine and phosphonate **33**. Phosphonate **33**, with *N*-Boc and 2-(trimethylsilyl)ethyl ester (TSE) protection (Schmidt *et al., Synthesis* **1984,** *53*; Kawai et al., *Chem. Lett.* **1990**, 577) was chosen because of the need for the resulting glycoamino

acids to be orthogonally suitable for peptide couplings in the presence of acetate carbohydrate protecting groups. The enamide ester **34** was obtained as a single geometric isomer in 88% yield for the 2-step procedure.

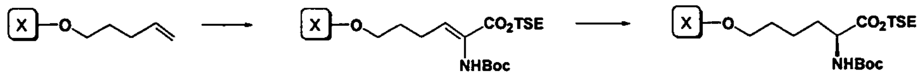
In one preferred embodiment, conditions for asymmetric hydrogenation of enamide ester **34** are detailed. The (*S*, *S*) ligand isomer of ethyl DuPHOS catalyst precursor was utilized, which has been well characterized in these types of systems to give the (*S*)-isomer in the amino acid product. The protected glycoamino acid was obtained in 98% yield and was determined to have been formed with a diastereomeric ratio (dr) of >20:1. Remarkably, the *t*-Boc protons are nearly baseline resolved and, in the asymmetric reaction, the minor isomer could not be detected. ^{13}C analysis also supports the conclusion that the minor isomer is not formed within the limit of NMR detection. Hydrogenation of **34** with an achiral catalyst (Pd/C, MeOH) produced a 1:1 mixture of R and S configured **35**, providing a comparison for diastereomeric ratio determination. This reaction also indicates that chirality transfer to yield **35** occurs from the chiral ligand and not carbohydrate derived substrate control. A final step to be performed prior to moving to synthesis and assembly of tumor antigens was that of demonstrating deprotectability of the blocking groups contained in the amino acid side chain. In the event, reaction of **35** with TBAF in THF gave acid **36**, suitably prepared for peptide coupling, in 93% yield.

With the general methodology demonstrated in the lactose model, in other preferred embodiments, advanced hexasaccharides **37** and **38**, as well as other antigens of interest, were investigated. As shown in Table 2, olefination of the peracetylated *n*-pentenyl glycoside of Globo-H, **37**, under the same conditions as those used in Figure 14, provided the corresponding enamide ester **41** in 72% yield as a single isomer and provided fucosyl GM1 hexasaccharide 16 in 10-22% yield. Notably, through use of the (*S*, *S*)-Et-DuPHOS-Rh^+ catalyst system, the hydrogenation of **41** and **42** proceeded in excellent yield producing **45** and **46** as single diastereomers by ^1H NMR analysis. Compounds **45** and **46** represent the first examples of synthetic glycoamino acids containing the complex oligosaccharides Globo-H and fucosyl GM_1.

Similar transformations on two other clinically promising antigens to generate their corresponding glycoamino acids were also performed in certain other embodiments.

As discussed previously, Lewis^{y} (Le^{y}) oligosaccharide has been identified as an important antigen for eliciting antibodies against colon, liver, prostate and ovarian carcinomas (Lloyd et al., *Am. J. Clin. Path.* **1987**, *87*, 129; Lloyd *et al.*, *Cancer Biol.* **1991**, *2*, 421; Yin et al., *Int. J. Cancer*, **1996**, *65*, 406). Previously, both a Le^{y} -KLH conjugate vaccine (Danishefsky *et al. J. Am. Chem. Soc.* **1995**, *117*, 5701) and a clustered Le^{y} glycopeptide (of natural α-*O*-linked configuration) glycoconjugate attached to either a glycolipid or KLH have been prepared, and have initiated human clinical trials against ovarian cancer with these vaccines have been initiated (Kudryashov *et al.*, *Cancer Immunol. Immunother.* **1998**, *45*, 281; Sabbatini *et al.*, *Int. J. Cancer* **2000**, *87*, 79).

The results starting with both Le^{y} *n*-pentenyl glycoside **39** and the α-linked *n*-pentenyl glycoside of the Tn antigen **40** (GalNAc) are presented in Table 2. The pentasaccharide **39** was available as an *intermediate in the synthesis of Le^{y} glycopeptide cluster* and consequently illustrates the potential advantage of this strategy. Thus, if immunogenicity is retained in the artificial constructs, these NPG derived glycoamino acids offer a much shorter synthetic route to vaccine glycoconjugates than their native counterparts. As shown in Table 2, olefination of **39** and **40** was uneventful and enamide esters **43** and **44** were obtained in 85% and 75% yields respectively, again as single isomers. Asymmetric hydrogenation, as before, also produced diastereomerically pure glycoamino acids **47** and **48** in excellent yields.



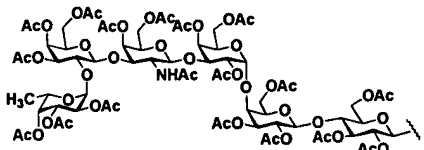
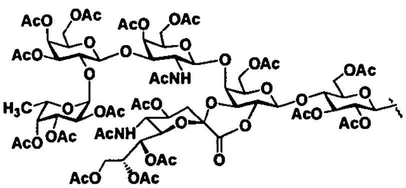
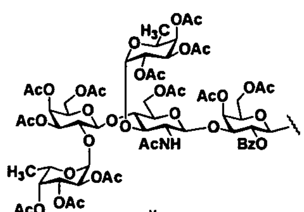
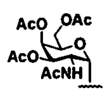
X =	Conditions: (1) 1. O_3, CH_2Cl_2, MeOH, pyr.; then Me_2S; (2) TMG, **33**, THF, -78 ¡C product, yield	Conditions: (*S, S*)-Et-DuPHOS-Rh^+ H_2, 50 psi, THF product, yield, dr
 Globo-H **(37)**	**41**, 72%	**45**, 98%, >20:1
 Fucosyl GM_1 **(38)**	**42**,10-22%	**46**, 93%, >20:1
 Le^y **(39)**	**43**, 85%	**47**, 99%, >20:1
 **(40)** α-Tn antigen	**44**, 75%	**48**, 99%, >20:1

Table 2

With the glycoamino acids as described above in hand, it would thus be desirable to generate novel glycopeptides. Specifically, in one embodiment, a novel glycopeptide incorporating globo-H, Le^y, and Tn is provided. Specifically, the *C*-terminus is modified to include a conjugation handle for carrier protein KLH. The mercaptoacetamide unit has proven to be effective for this purpose. As shown in Figure 15, the Tn glycoamino acid **48** was treated with TBAF to reveal the corresponding carboxylic acid. Coupling with a di-amino spacer terminated in a protected mercaptoacetamide ($AcSCH_2C(O)(CH_2)_3NH_2$) under the agency of the BOP reagent (benzotriazol-1-

oxytris(dimethylamino)phosphonium hexafluorophosphate) gave the corresponding amide in 50% yield for the 2 steps. Removal of the *N*-terminal Boc group gave amine **49** as its trifluoroacetate salt. The next antigen, Le^y, was prepared for coupling by reaction of **47** with TBAF to give acid **50**. Coupling of amine **49** with Le^y acid **50**, again with the BOP promoter, gave the Tn-Le^y di-peptide **51** in 86% yield. Lastly, Globo-H glycoamino acid **45** was treated with TBAF to give its corresponding acid **52**. Removal of the Boc protecting group in **51** followed by coupling with acid **52** gave the Tn-Le^y-Globo-H tri-peptide in 64% yield. Finally, the *N*-terminal Boc group was removed and the resulting anime capped as its acetate to give tripeptide **53** in 95% yield . With all components in place, the ester protecting groups were removed with hydrazine in degassed methanol to give the fully deprotected glycopeptide **54** (Figure 16) in excellent yield. As discussed below, the inventive glycopeptides prepared as detailed herein can also be conjugated to a suitable carrier protein or lipid.

2) Experimental **General.** DuPHOS-Rh^+ catalysts were purchased from Strem Chemical Co., Newburyport, MA. All other commercial materials (purchased from Aldrich-Sigma) were used without further purification. The following solvents were obtained from a dry solvent system (passed through a column of alumina): THF, diethyl ether (Et_2O), CH_2Cl_2, toluene and benzene. All reactions were performed under an atmosphere of dry N_2, unless otherwise noted. NMR (^1H and ^{13}C) spectra were recorded on a Bruker AMX-400 MHz or Bruker Advance DRX-500 MHz and referenced to residual solvent unless otherwise noted. IR spectra were recorded with a Perkin-Elmer 1600 series-FTIR spectrometer and optical rotations were measured with a Jasco DIP-370 digital polarimeter using a 10-cm path length cell. Low-resolution mass spectral analysis were performed with a JOEL JMS-DX-303 HF mass spectrometer. Analytical TLC was performed on E. Merck silica gel 60 F254 plates and flash column chromatography was performed using the indicated solvents on E. Merck silica gel 60 (40-63 mm) or Sigma H-type silica gel (10-40 mm).

Procedure for the synthesis of 40 (as shown in Figure 17)

Trichloroacetimidate d nor. The mixture of azidonitrates as shown in Figure 17 (1.66g, 4.41 mmol) was dissolved in CH_3CN (15 mL) and cooled to 0 °C. To the stirring solution was added Hunig's base (1.2 equiv., 0.925 mL) and benzene thiol (3.0 equiv., 1.35 mL). The reaction mixture was stirred at 0 °C for 1 hour and the ice bath was removed. After an additional 1 hour at room temperature, the reaction was concentrated under a stream of dry nitrogen. The resulting material was dissolved in a minimum amount of $CHCl_3$ and subjected to flash column chromatography (50% EtOAc/hexanes) to yield the hemiacetals (1.41, 97%). (Note 1: perform this flash in the hood, Note 2: isolate both anomers, which do separate on TLC/flash) The mixture of hemiacetals (1.41 g mg, 4.25 mmol) was dissolved in CH_2Cl_2 (8.5 mL) and trichloroacetonitrile (4.25 mL) was added, followed by K_2CO_3 (5.0 equiv., 2.93 g). The reaction stirred at room temperature overnight and was filtered through a plug of celite with additional methylene chloride. Concentration of the organic layer, followed by flash column chromatography (10->25% EtOAc/hexanes) gave the β-trichloroacetimidate (1.30 mg, 77%) as a yellow oil. (Note: α-anomer elutes first, then the β-anomer)

Pentenyl glycoside of α–Tn. The TCA-donor as shown in Figure 17 (1.30 g, 2.72 mmol) was dissolved in THF (0.2M, 13.6 mL) and pentenyl alcohol (5.0 equiv., 1.2 mL) and cooled to -10 °C (acetone-ice bath). A portion of TMSOTf (0.1 equiv., 0.049 mL) was added and the reaction stirred for 1 hour. Solid $NaHCO_3$ was added and the reaction was filtered through celite, concentrated and subjected to flash column chromatography (25% EtOAc/hexanes). (Note 1: The diastereomeric anomers do not separate. Their ratio is determined by ^1H NMR. Note 2: The starting materials and products co-elute by TLC - gradient TLC (10% first, then 50%) can be used to visualize the progress of the reaction.) The isolated glycosides were taken up in 10 mL of AcSH and stirred at rt for 2 days. Evaporation of the solvent by a stream of dry nitrogen followed by flash column chromatography (5% acetone/toluene -> 10% acetone/toluene) gave 620 mg of the α-glycoside (55%) and an undertermined amount of β-glycoside. (Note: Ethyl acetate/hexanes mixtures will also separate anomers, but actone/toluene was

determined to be superior.)

General procedure for olefination, 41. The preparation of enamide **41** (Globo-H) is representative of this procedure. The *n*-pentenyl glycoside **37** (58 mg, 0.0322 mmol) was dissolved in 10:10:1 MeOH:CH_2Cl_2:pyridine (3 mL, typically 0.05 M-0.01 M) and cooled to -78 °C. A stream of dry ozone was passed through the reaction mixture until a pale blue color persisted. The ozone source was removed and the reaction stirred at -78 °C for an additional 15 minutes, upon which time a stream of dry nitrogen was applied to remove excess ozone. Dimethyl sulfide (50 equivs., 0.118 mL) was added to the cooled mixture, the ice bath was removed and the reaction was allowed to stir at rt for 4 hours. The reaction was diluted with CH_2Cl_2 (10mL), washed with water (50mL), and back-extracted with additional CH_2Cl_2 (2x10 mL). The combined organic layer was dried over anhydrous $MgSO_4$ and concentrated. The crude aldehyde was typically not purified, but was azeotroped dry with anhydrous benzene (3x3 mL) and used directly in the next step.

Phosphonate **33** (1.20 equivs., 14 mg) was dissolved in anhydrous THF (0.3 mL), cooled to -78 °C and tetramethyl guanidine (TMG) (1.25 equivs., 0.005 mL) was added dropwise. The reaction stirred at -78 for 30 minutes, followed by addition of the crude aldehyde (0.0322 mmol) in additional THF (2x0.3 mL, typically 0.1-0.01 M total reaction volume). The reaction was allowed to stir to rt overnight (10-15h), was extracted with EtOAc (10mL), washed with 0.05 M aqueous HCl (50mL) and back-extracted with additional EtOAc (2x10 mL). (Note: All the TMG must be removed prior to asymmetric hydrogenation.) The combined organic layer was dried over $MgSO_4$, concentrated and purified by flash column chromatography (75% EtOAc/hexanes -> 100 % EtOAc) to yield the desired enamide ester **41** as a single isomer. 72%, white foam; R_f 0.85 (100% EtOAc); IR ($CDCl_3$ film) 3373, 2956, 2951, 1748, 1370, 1069 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 6.65 (d, 1H, J=6.4 Hz), 6.44 (m ,1H), 6.07 (bs, 1H), 5.56 (d, 1H, J=3.1 Hz), 5.44 (d, 1H, J=3.4 Hz), 5.37 (d, 1H, J=3.3 Hz), 5.27 (dd, 1H, J=10.9, 3.0 Hz), 5.22 (d, 1H, J=2.6 Hz), 5.20-5.17 (m, 2H), 5.15 (d, 1H, J=2.1 Hz), 5.13 (d, 1H, J=4.9 Hz), 5.09 (dd, 1H, J=10.7, 7.3 Hz), 5.03 (dd, 1H, J=11.1, 3.3 Hz), 4.96 (dd, 1H, J=9.6, 3.5 Hz), 4.92 (dd, 1H, J=11.2, 3.4 Hz), 4.85 (dd, 1H, J=9.6, 8.0 Hz), 4.73 (dd, 1H, J=10.9, 2.5 Hz), 4.50-4.38 (m, 6H), 4.34 (t, 1H, J=6.2 Hz), 4.26-4.21 (m, 3H), 4.16-4.02 (m, 8H),

3.98 (d, 1H, J=2.0 Hz), 3.94 (t, 1H, J=6.4 Hz), 3.86-3.72 (m, 6H), 3.60-3.57 (m, 1H), 3.48-3.46 (m, 1H), 2.94-2.89 (m, 1H), 2.17-2.14 (m, 1H), 2.11-2.08 (m, 1H), 2.04 (s, 3H), 2.038 (s, 3H), 2.033 (s, 6H), 1.99 (s, 3H), 1.98 (s, 3H), 1.97 (s, 3H), 1.967 (s, 3H), 1.962 (s, 3H), 1.95 (s, 3H), 1.92 (s, 9H), 1.89 (s, 3H), 1.857 (s, 3H), 1.854 (s, 3H), 1.78 (s, 3H), 1.63-1.59 (m, 2H), 1.34 (s, 9H), 1.04 (d, 3H, J=6.5 Hz), 0.93-0.90 (m, 2H), -0.06 (s, 9H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 172.20, 171.44, 170.94, 170.65, 170.52, 170.48, 170.44, 170.36, 170.29, 170.21, 170.17, 169.97, 169.63, 169.49, 169.31, 168.85, 164.78, 153.19, 134.70, 126.80, 102.35, 101.99, 101.26, 100.25, 99.12, 998.66, 94.21, 80.24, 76.88, 75.98, 73.61, 73.36, 73.08, 72.80, 72.56, 72.37, 71.81, 71.68, 71.46, 71.28, 70.78, 70.69, 70.67, 70.37, 70.06, 70.01, 68.92, 68.82, 67.99, 67.95, 67.54, 67.28, 66.94, 64.42, 62.14, 61.67, 61.29, 61.09, 60.92, 56.16, 28.12, 27.98, 24.52, 23.80, 23.03, 20.81, 20.73, 20.70, 20.68, 20.64, 20.60, 20.59, 20.54, 20.46, 20.40, 17.37, 17.24, 15.85, 15.48, 14.01, -1.58; HRMS (FAB) cald. for $C_{88}H_{128}N_2O_{51}SiNa$ 2079.7145, found 2079.7174.

Lactose Enamide 34. 88%, white foam; R_f 0.45 (66% EtOAc/hexanes); IR ($CDCl_3$ film) 3407, 3146, 2954, 2898, 1752, 1654, 1233, 1167, 1055 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 6.34 (m, 1H), 6.03 (bs, 1H), 5.22 (d, 1H, J=3.2 Hz), 5.07 (t, 1H, J=9.4 Hz), 4.99 (dd, 1H, J=10.3, 7.9 Hz), 4.83 (dd, 1H, J=10.5, 3.3 Hz), 4.77 (t, 1H, J=9.3 Hz), 4.37-4.33 (m, 3H), 4.20-4.11 (m, 3H), 4.08-4.00 (m, 3H), 3.82-3.65 (m, 5H), 3.49-3.46 (m, 1H), 3.39-3.34 (m, 1H), 2.16-2.14 (m, 1H), 2.11-2.09 (m, 1H), 2.04 (s, 3H), 2.02 (s, 3H), 1.94 (s, 3H), 1.93 (s, 3H), 1.92 (s, 6H), 1.84 (s, 3H), 1.62-1.59 (m, 2H), 1.34 (s, 9H), 0.94-0.89 (m, 2H), 0.05 (s, 9H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.29, 170.21, 170.03, 169.94, 169.66, 169.50, 168.97, 164.77, 153.20, 134.70, 100.97, 100.31, 80.23, 76.17, 72.69, 72.51, 71.56, 70.87, 70.52, 68.95, 68.83, 66.47, 63.54, 61.88, 60.66, 33.81, 28.05, 27.92, 24.47, 20.73, 20.68, 20.57, 20.51, 20.39, 17.21, -1.60; HRMS (FAB) cald. for $C_{43}H_{67}NO_{21}SiNa$ 986.4013, found 986.4029.

Lewis^{y} enamide 43. 85%, white foam; R_f 0.45 (75% EtOAc/hexanes); IR ($CDCl_3$ film) 3371, 2965, 2956, 1746, 1371, 1231, 1069 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 7.94 (d, 2H, J=7.2 Hz), 7.48 (t, 1H), 7.36 (t, 2H), 6.21 (t, 1H), 5.71 (m, 1H), 5.38 (d, 1H, J=3.2 Hz), 5.29 (dd, 1H, J=10.8, 8.8 Hz), 5.22-5.19 (m, 4H), 5.05-4.78 (m, 10H), 4.43 (dd, 1H,

J=14.1, 8.0 Hz), 4.36 (dd, 1H, J=9.7, 5.1 Hz), 4.27 (m, 1H), 4.15-4.30 (m, 5H), 3.86 (dd, 1H, J=10.1, 3.3 Hz), 3.78-3.71 (m, 3H), 3.62 (dd, 1H, J=9.8, 1.7 Hz), 3.30 (d, 1H, J=9.6 Hz), 3.18-3.08 (m, 1H), 3.04 (bm, 1H), 2.08 (s, 3H), 2.04 (s, 6H), 2.01 (s, 3H), 1.99 (s, 9H), 1.98 (s, 3H), 1.94 (s, 3H), 1.89 (s, 3H), 1.88 (s, 3H), 1.86 (s, 3H), 1.83 (s, 3H), 1.55-1.52 (m, 2H), 1.32 (s, 9H), 1.01-1.00 (m, 6H), 0.91-0.88 (m, 2H), -0.07 (s, 9H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 172.56, 172.40, 172.28, 172.11, 172.06, 172.04, 171.87, 171.77, 171.57, 171.43, 171.20, 171.06, 166.69, 166.32, 154.76, 136.48, 135.14, 131.29, 130.76, 130.19, 127.93, 102.82, 101.83, 101.72, 97.65, 97.11, 81.66, 75.40, 74.80, 74.55, 74.32, 74.01, 72.87, 72.65, 72.35, 72.28, 71.14, 70.66, 69.73, 69.28, 69.15, 69.02, 68.34, 66.43, 65.38, 64.92, 63.36, 62.05, 61.80, 59.87, 29.66, 29.62, 29.48, 25.83, 24.02, 22.51, 22.46, 22.31, 22.14, 22.12, 22.09, 22.0o3, 18.75, 17.30, 17.00, 15.63, -0.04; HRMS cald. for $C_{79}H_{112}N_2O_{41}SiNa$, found x.

Tn enamide 44. 75%, white foam; R_f 0.80 (100% EtOAc); IR ($CDCl_3$ film) 3340, 3071, 2954, 1715, 1663, 1498, 1369, 1218, 1162, 1049 cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 6.38 (bs, 1H), 6.15 (bs, 1H), 5.26 (d, 1H, J=2.7 Hz), 5.02 (dd, 1H, J=11.5, 3.2 Hz), 4.79 (s, 1H), 4.48-4.42 (m, 1H), 4.16-4.12 (m, 2H), 4.03 (m, 1H), 3.99-3.92 (m, 2H), 3.62-3.56 (m, 1H), 3.40-3.35 (m, 1H), 2.26-2.16 (m, 2H), 2.03 (s, 3H), 1.92 (s, 3H), 1.86 (s, 3H), 1.84 (s, 3H), 1.67 (s, 3H), 1.33 (s, 9H), 0.94-0.9 (m, 2H), -0.06 (s, 9H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 170.28, 170.11, 170.06, 164.70, 134.6, 108.73, 97.26, 80.31, 67.95, 67.05, 66.35, 63.51, 61.67, 47.46, 27.87, 27.49, 22.78, 20.43, 17.05, -1.74; HRMS (FAB) cald. for $C_{30}H_{51}N_2O_{13}SiNa$ 675.3160, found 675.3124.

Fucosyl GM$_1$ enamide 42. 10-22%; R_f 0.25 (10% MeOH/EtOAc); ^{1}H NMR (MeOH, 500 MHz) δ 7.94 (d, 2H, J=7.2 Hz), 7.48 (t, 1H), 7.36 (t, 2H), 6.21 (t, 1H), 5.71 (m, 1H), 5.38 (d, 1H, J=3.2 Hz), 5.29 (dd, 1H, J=10.8, 8.8 Hz), 5.22-5.19 (m, 4H), 5.05-4.78 (m, 10H), 4.43 (dd, 1H, J=14.1, 8.0 Hz), 4.36 (dd, 1H, J=9.7, 5.1 Hz), 4.27 (m, 1H), 4.15-4.03 (m, 5H), 3.86 (dd, 1H, J=10.1, 3.3 Hz), 3.78-3.71 (m, 3H), 3.62 (dd, 1H, J=9.8, 1.7 Hz), 3.39-3.37 (m, 1H), 3.30 (bd, 1H, J=9.6 Hz), 3.18-3.08 (m, 1H), 3.04 (bm, 1H), 2.08 (s, 3H), 2.04 (s, 6H), 2.01 (s, 3H), 1.99 (s, 9H), 1.98 (s, 3H), 1.94 (s, 3H), 1.89 (s, 3H), 1.88 (s,

3H), 1.86 (s, 3H), 1.83 (s, 3H), 1.5-1.52 (m, 2H), 1.32 (s, 9H), 1.01-1.00 (m, 6H), 0.91-0.88 (m, 2H), -0.07 (s, 9H).

General procedure for asymmetric hydrogenation. Under an inert deoxygenated atmosphere, [(COD)Rh-((*S*, *S*)-Et-DuPHOS)]$^+$OTf$^-$ (0.005 mmol, 5 mol%) and the desired enamide ester (0.100 mmol) were dissolved in deoxygenated anhydrous THF (10 mL, 0.01 M) in a Fischer-Porter tube. The reaction vessel was pressurized with 50 psi of H_2 after three vacuum/H_2 cycles and stirred at 25 °C for 24-36 hours, or until the reaction turned from light orange to brown in color. The vessel was depressurized, the mixture concentrated and purified through a short plug of silica gel to yield the glycoamino acid.

Lactose glycoamino acid 35. 98%; R_f 0.45 (66% EtOAc/hexanes); ^{1}H NMR (C_6D_6, 500 MHz) δ 5.54 (dd, 1H, J=10.4, 8.0 Hz), 5.48 (d, 1H, J=3.2 Hz), 5.39 (t, 1H, J=9.2 Hz), 5.21 (dd, 1H, J=6.2, 1.1 Hz), 5.12 (d, 1H, J=3.1 Hz), 5.09 (d, 1H, J=3.3 Hz), 4.54-4.51 (m, 2H), 4.33 (d, 1H, J=7.8 Hz), 4.19-4.06 (m, 6H), 3.74-3.58 (m, 2H), 3.49-3.40 (m, 1H), 3.38 (d, 1H, J=10.9 Hz), 3.23-3.16 (m, 2H), 1.96 (s, 3H), 1.94 (s, 3H), 1.90 (s, 3H), 1.74 (s, 3H), 1.73 (s, 3H), 1.64 (s, 3H), 1.51 (s, 3H), 1.45 (s, 9H), 0.91-0.88 (m, 2H), -0.10 (s, 9H); ^{13}C NMR (C_6D_6, 100 MHz) δ 173.26, 170.44, 170.41, 170.18, 170.09, 169.35, 156.05, 102.98, 101.06, 79.73, 77.59, 74.13, 73.21, 72.73, 71.94, 71.19, 70.10, 69.58, 67.28, 63.76, 63.01, 61.25, 54.41, 34.76, 32.76, 28.62, 28.80, 25.75, 22.45, 21.18, 20.93, 20.84, 20.76, 20.57, 20.46, 20.15, 17.83, -1.29; HRMS (FAB) cald. for $C_{42}H_{67}NO_{22}SiNa$ 988.3870, found 988.3821.

Globo-H glycoamino acid 45. 98%; IR ($CDCl_3$ film) 3373, 2956, 2951, 1748, 1370, 1069 cm^{-1}; ^{1}H NMR (C_6D_6, 500 MHz) δ 6.54 (d, 1H, J=6.5 Hz), 5.89 (d, 1H, J=3.5 Hz), 5.86 (d, 1H, J=3.1 Hz), 5.74-5.69 (m, 3H), 5.50-5.46 (m, 2H), 5.39-5.34 (m, 2H), 5.31 (dd, 1H, J=13.4, 0.7 Hz), 5.26 -5.19 (m, 2H), 5.15 (d, 1H, J=8.1 Hz), 5.09-5.06 (m, 3H), 4.82 (dd, 1H, J=10.9, 2.5 Hz), 4.74-4.72 (m, 1H), 4.70-4.69 (m, 1H), 4.66 (t, 1H), 4.58-4.49 (m, 3H), 4.45-4.41 (m, 2H), 4.37-4.33 (m, 2H), 4.24-4.22 (m, 2H), 4.20-4.12 (m, 3H), 4.04-4.01 (m, 2H), 3.91-3.86 (m, 3H), 3.71-3.69 (m, 2H), 3.64-3.57 (m, 2H), 4.43 (t, 1H) , 3.28-3.27 (m, 1H), 3.23-3.21 (m, 1H), 2.38 (s, 3H), 2.30 (s, 3H), 2.19 (s, 3H), 2.01

(s, 3H), 1.98 (s, 3H), 1.93 (s, 3H), 1.92 (s, 3H), 1.90 (s, 3H), 1.89 (s, 3H), 1.88 (s, 3H), 1.84 (s, 3H), 1.82 (s, 3H), 1.75 (s, 3H), 1.73 (s, 3H), 1.71 (s, 3H), 1.68 (s, 3H), 1.64 (s, 3H), 1.61 (s, 3H), 1.46 (s, 3H), 1.45 (s, 9H), 1.26-1.22 (m, 2H), 1.08 (d, 3H, J=6.5 Hz), 0.89 (t, 2H), -0.10 (s, 9H); ^{13}C NMR ($CDCl_3$, 125 MHz) δ 172.87, 172.28, 171.52, 170.77, 170.61, 170.56, 170.45, 170.40, 170.29, 170.07, 169.75, 169.58, 169.44, 168.95, 155.38, 102.00, 101.29, 100.38, 99.21, 98.77, 94.31, 73.65, 73.34, 73.10, 72.61, 72.38, 71.84, 71.65, 71.58, 71.30, 70.81, 70.68, 70.17, 70.06, 69.59, 69.09, 68.85, 68.05, 67.99, 67.56, 67.30, 64.46, 63.64, 62.16, 61.74, 61.35, 61.12, 60.96, 56.11, 53.45, 32.30, 29.65, 28.96, 28.29, 28.10, 23.11, 21.69, 20.88, 20.85, 20.80, 20.76, 20.72, 20.67, 20.62, 20.55, 20.48, 17.31, 15.88, -1.55; HRMS (FAB) cald. for $C_{88}H_{130}N_2O_{51}SiNa$ 2081.7302, found 2081.7247.

Lewis^y glycoamino acid 42. 99%; IR ($CDCl_3$ film) cm^{-1}; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 8.24 (d, 2H, J=8.4 Hz), 7.27-7.18 (m, 3H), 5.83 (dd, 1H, J=10.1, 8.0), 5.78 (d, 1H, J=3.2 Hz), 5.76 (d, 1H, J=3.0 Hz), 5.74-5.71 (m, 2H), 5.69 (d, 1H, J=3.2 Hz), 5.66 (d, 1H, J=3.3Hz), 5.55 (d, 1H, J=3.3 Hz), 5.50 (m, 1H), 5.47 (d, 1H, J=3.8 Hz), 5.41-5.27 (m, 5H), 4.93 (d, 1H, J=7.8 Hz), 4.86 (d, 1H, J=8.6 Hz), 4.77-4.70 (m, 2H), 4.62 (d, 1H, J=7.8 Hz), 4.56-4.53 (m, 1H), 4.47-4.35 (m, 5H), 4.34-4.25 (m, 4H), 4.11-4.00 (m, 5H), 3.92-3.89 (m, 1H), 3.75-3.65 (m, 3H), 3.64-3.61 (t, 1H), 3.28-2.24 (m, 1H), 2.22 (s, 3H), 2.21 (s, 3H), 1.93 (s, 3H), 1.90 (s, 3H), 1.82 (s, 3H), 1.78 (s, 3H), 1.73 (s, 3H), 1.72 (s, 3H), 1.66 (s, 3H), 1.65 (s, 3H), 1.64 (s, 3H), 1.63 (s, 3H), 1.51 (s, 3H), 1.50 (d, 3H, J=6.5 Hz), 1.46 (s, 9H), 1.38 (d, 3H, J=6.5 Hz), 1.33-1.27 (m, 2H), 1.22-1.21 (m, 2H), 0.91-0.80 (m, 4H), -0.12 (s, 9H); ^{13}C NMR (C_6D_6, 100 MHz) δ 172.86, 171.05, 170.59, 170.52, 170.46, 170.37, 170.26, 170.01, 169.97, 169.90, 165.44, 155.61, 133.24, 130.40, 101.59, 100.98, 100.71, 97.09, 96.21, 79.22, 76.42, 74.77, 74.04, 73.69, 72.03, 71.65, 71.14, 70.14, 69.20, 68.66, 68.55, 68.20, 67.99, 67.25, 65.67, 64.56, 63.23, 62.41, 61.33, 60.94, 58.23, 53.84, 39.12, 32.25, 29.30, 28.41, 22.88, 22.01, 20.93, 20.66, 20.58, 20.47, 20.40, 20.18, 20.02, 17.40, 16.36, 15.94, -1.62; HRMS (FAB) cald. for $C_{79}H_{114}N_2O_{41}SiNa$ 1797.6558, found 1797.6528.

Tn glycoamino acid 43. 99%; IR ($CDCl_3$ film) 3362, 2954, 2990, 2871, 1749, 1716, 1683, 1668, 1520, 1369, 1249, 1164, 1047 cm^{-1}; ^1H NMR ($CDCl_3$, 400 MHz) δ 5.66 (d, 1H, J=9.3 Hz), 5.24 (d, 1H, J=2.8 Hz), 5.03 (dd, 1H, J=11.4, 3.3 Hz), 4.98 (d, 1H, J=8.1), 4.73 (d, 1H, J=3.3 Hz), 4.48-4.42 (m, 1H), 4.17-4.07 (m, 3H), 4.05-3.93 (m, 3H), 3.59-3.54 (m, 1H), 3.33-3.27 (m, 1H), 2.04 (s, 1H), 1.93 (s, 3H), 1.87 (s, 3H), 1.86 (s, 3H), 1.73-1.70 (m, 1H), 1.57-.150 (m, 3H), 1.31 (s, 9H), 0.91-0.87 (m, 2H), -0.06 (s, 9H); ^{13}C NMR (C_6D_6, 100 MHz) δ 173.44, 171.04, 170.57, 170.35, 169.89, 156.06, 98.59, 79.82, 69.29, 68.30, 68.07, 67.43, 64.01, 62.33, 54.33, 48.63, 32.87, 29.05, 28.76, 23.24, 22.82, 20.89, 20.66, 20.47, 17.85, -1.28; HRMS (FAB) cald. for $C_{30}H_{53}N_2O_{13}SiNa$ 677.3316, found 677.3352.

General procedure for *N*-Boc deprotection. The desired glycoamino acid (0.100 mmol) was dissolved in CH_2Cl_2 (3.0mL) with stirring. Trifluoroacetic acid (TFA) (3.0mL) was added dropwise and the reaction stirred at rt for 1 hour. The mixture was then concentrated with a stream of dry N_2 and azeotroped with anhydrous benzene (2x5mL) to give the crude amine as its TFA salt which was typically used without further purification.

General procedure for TSE ester deprotection. The desired glycoamino acid (0.100 mmol) was dissolved in THF (1.0-3.0 mL) and cooled to 0 °C. A 1.0 M solution of TBAF in THF (0.250 mmol, 2.5 equivs.) was added dropwise, the ice bath removed and the reaction stirred at rt for 1-2 hour, as judged by TLC. (Note: prolonged reaction times, i.e. >10 h, may result in deacetylation.) The reaction mixture was diluted with CH_2Cl_2 (10mL), washed with 0.05M aqueous HCL (50 mL), and back-extracted with additional CH_2Cl_2 (2x10 mL). The combined organic layer was dried over anhydrous Mg_2SO_4 and concentrated. The crude acid was typically used without further purification. **Acid 36**: ^1H NMR ($CDCl_3$, 400 MHz) δ 5.22 (d, 1H, J=2.8 Hz), 5.07 (t, 1H, J=9.3 Hz), 4.98 (dd, 1H, J=10.4, 5.9 Hz), 4.84 (dd, 1H, J=10.4, 3.5 Hz), 4.75 (dd, 1H, J=9.5, 8.0 Hz), 4.42-4.35 (m, 2H), 4.34-4.31 (m, 1H), 4.15-4.14 (m, 1H), 4.03-3.94 (m, 4H), 3.77-3.65 (m, 5H), 3.49-3.45 (m, 1H), 3.37-3.33 (m, 1H), 3.10-3.07 (m, 1H), 2.03 (s, 3H), 2.00 (s, 3H), 1.96 (s, 3H), 1.94 (s, 3H), 1.92 (s, 3H), 1.84 (s, 3H), 1.51-1.46 (m, 4H), 1.32 (s, 9H).

General procedure for BOP reagent promoted peptide coupling. The desired amine and acid (equimolar amounts) were azeotroped together with anhydrous benzene and dried under high vacuum. The mixture was dissolved in CH_2Cl_2 (0.1-0.05M), BOP reagent (1.25 equivs) was added and the solution cooled to 0 °C over 15 minutes. A dropwise addition of Hunig's base (15 equivs.) was followed by removal of the ice bath. The reaction stirred at rt for 2-4 h, as judged by TLC. Concentration of the reaction mixture was followed by purification by flash column chromatography. In cases where bi-product HMPA was difficult to remove, the peptide was subjected to sephadex purification (LH-20, MeOH).

***N*-Boc Tn with mercatoacetamide spacer.** 54%, colorless oil; R_f 0.35 (10% MeOH/EtOAc); IR ($CDCl_3$ film) 3303, 3078, 2974, 2935, 2872, 1748, 1703, 1692, 1658, 1535, 1440, 1369, 1245, 1166 cm^{-1}; ^{1}H NMR (MeOH, 400 MHz) δ 5.40 (d, 1H, J=2.9 Hz), 5.13 (dd, 1H, J=11.6, 3.2 Hz), 4.42 (dd, 1H, J=11.5, 3.5 Hz), 4.23 (t, 1H, J=6.7 Hz), 4.14-4.05 (m, 2H), 3.96 (m, 1H), 3.74-3.69 (m, 1H), 3.60 (s, 2H), 3.49-4.44 (m, 1H), 3.26-3.13 (m, 5H), 2.36 (s, 3H), 2.12 (s, 3H), 2.02 (s, 3H), 1.94 (s, 3H), 1.93 (s, 3H), 1.67-1.59 (m, 6H), 1.43 (s, 9H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 195.59, 172.53, 170.78, 170.54, 170.39, 170.30, 168.51, 155.62, 97.59, 79.95, 68.29, 67.96, 67.26, 66.38, 61.83, 60.28, 54.58, 47.62, 36.47, 35.97, 33.02, 31.92, 30.18, 29.14, 28.37, 28.17, 23.07, 22.35, 20.68, 20.64; HRMS (MALDI) cald. for $C_{32}H_{52}N_4O_{14}SNa$ 771.3093, found 771.3070.

Le^Y/Tn dipeptide 51. 86%, white film; R_f 0.65 (20% MeOH/EtOAc); ^{1}H NMR (MeOH, 400 MHz) δ 8.06 (d, 2H, J=7.4 Hz), 7.63 (t, 1H), 7.51 (t, 2H), 5.55 (d, 1H, J=3.3 Hz), 5.40 (d, 1H, 2.7 Hz), 5.38 (d, 1H, J=2.7 Hz), 5.32 (d, 1H, J=3.3 Hz), 5.29 (d, 1H, J=4.1 Hz), 5.26 (d, 1H), 5.21-5.12 (m, 5H), 5.01 (q, 1H), 4.93 (m, 2H), 4.90 (m, 2H), 4.79 (d, 1H, J=10.8 Hz), 4.71 (d, 1H), 4.64 (d, 1H), 4.50-4.01 (m, 15H), 3.88-3.60 (m, 7H), 3.60 (s, 2H), 3.51-3.42 (m, 2H), 3.20-3.13 (m, 5H), 2.36 (s, 3H), 2.20 (s, 3H), 2.16 (s, 3H), 2.15 (s, 3H), 2.13 (s, 3H), 2.11 (s, 3H), 2.09 (s, 3H), 2.08 (s, 3H), 2.07 (s, 3H), 2.05 (s, 3H), 2.02 (s, 6H), 1.97 (s, 6H), 1.95 (s, 3H), 1.94 (s, 9H), 1.91 (s, 3H), 1.68-1.63 (m, 8H), 1.44 (s, 9H), 1.15 (d, 3H, J=6.3 Hz), 1.14 (d, 3H, J=6.3 Hz); ^{13}C NMR (MeOH, 100

MHz) δ 196.26, 175.39, 174.30, 173.75, 173.22, 172.80, 172.72, 172.56, 172.51, 172.44, 172.39, 172.30, 172.19, 172.12, 171.85, 171.75, 171.64, 170.76, 166.77, 158.24, 134.92, 131.29, 131.10, 129.99, 103.53, 102.80, 101.77, 99.12, 97.81, 97.30, 80.90, 78.50, 75.88, 75.11, 74.65, 74.32, 73.01, 72.70, 72.56, 72.47, 72.18, 71.91, 70.86, 69.84, 69.62, 69.42, 69.09, 68.90, 67.84, 66.43, 65.43, 63.50, 63.21, 62.57, 61.68, 56.42, 55.96, 54.89, 38.21, 37.74, 37.12, 33.89, 32.72, 30.42, 30.21, 30.01, 28.92, 23.72, 23.44, 22.93, 22.73, 21.32, 21.13, 20.97, 20.86, 20.74, 20.60, 16.67, 16.29; HRMS (MALDI) cald. for $C_{101}H_{144}N_6O_{52}SiNa$ 2327.8421, found 2327.8536.

***N*-Boc Globo-H/Le^y/Tn tripeptide**. 64%, white film; R_f 0.45 (10% MeOH/EtOAc); ^{1}H NMR (MeOH, 400 MHz) δ 8.05 (d, 2H, J=7.4 Hz), 7.63 (t, 1H), 7.50 (t, 2H), 5.64 (d, 1H, J=2.8 Hz), 5.55 (d, 1H, J=3.6 Hz), 5.43 (d, 1H, J=3.2 Hz), 5.40 (d, 1H, J=2.4 Hz), 5.37 (d, 1H, J=2.5 Hz), 5.32-5.25 (m, 7H), 5.23-5.12 (m, 10H), 5.08-5.05 (m, 2H), 5.00 (d, 1H, J=7.5 Hz), 4.96 (d, 1H, J=3.1 Hz), 4.94 (m, 2H), 4.90 (m, 2H), 4.86 (m, 2H), 4.82-4.77 (m, 3H), 4.72-4.70 (m, 3H), 4.64-4.59 (m, 3H), 4.51-4.35 (m, 9H), 4.32-3.92 (m, 31H), 3.86-3.67 (m, 13H), 3.60 (s, 2H), 3.59 (m, 1H), 3.51 (m, 1H), 3.47-3.44 (m, 2H), 3.24-3.18 (m, 5H), 2.36 (s, 3H), 2.19 (s, 3H), 2.17 (s, 3H), 2.16 (s, 3H), 2.15 (s, 3H), 2.14 (s, 3H), 2.138 (s, 3H), 2.133 (s, 3H), 2.12 (s, 3H), 2.116 (s, 3H), 2.115 (s, 3H), 2.10 (s, 3H), 2.096 (s, 3H), 2.090 (s, 3H), 2.08 (s, 3H), 2.07 (s, 3H), 2.05 (s, 6H), 2.04 (s, 3H), 2.039 (s, 3H), 2.031 (s, 9H), 2.02 (s, 6H), 2.00 (s, 3H), 1.97 (s, 3H), 1.96 (s, 3H), 1.94 (s, 18H), 1.93 (s, 3H), 1.91 (s, 3H), 1.86 (s, 3H), 1.67-1.52 (m, 16H), 1.43 (s, 9H), 1.32 (d, 3H), 1.16-1.13 (m, 6H).

***N*-Ac capped Globo-H/Le^y/Tn tripeptide 53.** 95%, white film; R_f 0.35 (10% MeOH/EtOAc); ^{1}H NMR ($CDCl_3$, 500 MHz) δ 8.00 (d, 2H, J=7.3 Hz), 7.59 (t, 1H), 7.47 (t, 2H), 6.70 (d, 1H, J=6.3 Hz), 6.61 (d, 1H, J=9.8 Hz), 5.56 (d, 1H, J=2.9 Hz), 5.47 (d, 1H, J=2.1 Hz), 5.44 (d, 1H, J=3.4 Hz), 5.37 (d, 1H, J=3.2 Hz), 5.34 (d, 1H, J=2.7 Hz), 5.32-5.28 (m, 7H), 5.28 (d, 1H), 5.22-5.19 (m, 3H), 5.15-5.10 (m, 6H), 5.08 (m, 1H), 5.06 (m, 1H), 5.01-4.87 (m, 13H), 4.85-4.82 (m, 1H), 4.55-4.35 (m, 15H), 4.26-4.23 (m, 4H), 4.15-4.02 (m, 20H), 3.98-3.93 (m, 5H), 3.88-3.72 (m, 12H), 3.66 (m, 1H), 3.59-3.58 (m, 1H), 3.52 (s, 2H), 3.49-3.38 (m, 5H), 3.20 (m, 6H), 3.02-2.98 (m, 1H), 2.37 (s, 3H),

2.17 (s, 3H), 2.139 (s, 6H), 2.133 (s, 6H), 2.12 (s, 6H), 2.11 (s, 3H), 2.10 (s, 3H), 2.08 (s, 12H), 2.07 (s, 3H), 2.06 (s, 12H), 2.05 (s, 3H), 2.046 (s, 3H), 2.041 (s, 3H), 2.03 (s, 3H), 2.019 (s, 3H), 2.015 (s, 9H), 1.98 (s, 3H), 1.97 (s, 6H), 1.955 (s, 3H), 1.951 (s, 3H), 1.94 (s, 3H), 1.92 (s, 3H), 1.88 (s, 3H), 1.76-1.57 (m, 10H), 1.44-1.41 (m, 4H), 1.38-1.30 (m, 4H), 1.23-1.20 (m, 2H), 1.13-1.09 (m, 9H).

Fully Deprotected Globo-H/Le^{Y}/Tn tripeptide 54. 98%, white film; ^{1}H NMR (D_2O, 500 MHz) δ 5.30 (s, 1H, J=2.8 Hz), 5.25 (d, 1H, J=3.7 Hz), 5.13 (d, 1H, J=3.5 Hz), 4.91-4.87 (m, 3H), 4.75-4.74 (m, 1H), 4.63 (d, 1H, J=7.4 Hz), 4.57-4.48 (m, 3H), 4.41-4.38 (m, 2H), 4.31 (m, 1H), 4.29-4.24 (m, 6H), 4.18-4.12 (m, 3H), 4.05-3.56 (m, 58H), 3.50-3.46 (m, 3H), 3.32-3.24 (m, 5H), 2.06 (s, 3H), 2.05 (s, 3H), 2.04 (s, 6H), 1.82-1.65 (m, 14H), 1.47-1.42 (m, 6H), 1.29 (d, 3H, J=6.5 Hz), 1.25 (d, 3H, J=7.4 Hz), 1.23 (d, 3H, J=7.0 Hz); ^{13}C NMR (D_2O, 125 MHz) δ 175.11, 174.85, 174.81, 174.68, 174.44, 174.25, 174.13, 171.64, 164.59, 104.37, 103.71, 103.25, 102.78, 102.39, 102.44, 100.83, 100.59, 99.80, 99.67, 98.96, 97.34, 82.76, 79.18, 78.65, 77.55, 76.74, 76.50, 75.88, 75.78, 75.45, 75.24, 75.18, 75.00, 74.90, 73.96, 73.47, 73.35, 72.50, 72.32, 72.24, 72.09, 71.31, 71.24, 70.53, 70.44, 70.40, 70.16, 70.11, 69.90, 69.57, 69.50, 69.12, 68.93, 68.87, 68.66, 68.42, 68.22, 68.12, 68.08, 67.29, 67.17, 61.85, 61.68, 61.37, 61.34, 61.20, 60.74, 60.48, 60.19, 56.57, 54.02, 52.02, 50.41, 41.31, 37.09, 31.07, 30.79, 28.69, 28.64, 28.36, 22.72, 22.64, 22.40, 22.36, 22.25, 22.05, 22.01, 21.97, 21.93, 21.87, 21.84, 15.84, 15.70.

3) Preparation of Polycarbohydrate (globo H, Le^{y}, Tn) cluster-KLH conjugate using bifunctional cross linker method:

Polycarbohydrate (globo H, Le^{y}, Tn) cluster is conjugated as described below using maleimidobenzoyl-N-hydroxysuccinimide ester (MBS) which is a heterobifunctional reagant. At neutral pH it crosslinks amino groups with succinimide and then with thiol groups with maleimide. The thiol group is provided by the cysteine residue of peptide backbone of cluster and the amino groups by the N-terminal and lysine side-chain of the KLH. After linkage MBS to KLH the unreacted MBS is purified by column and cross-linked to cysteine on the synthetic polycarbohydrate cluster. The unbound antigen is removed by passage of the reaction mixture through a CentriPrep 30 filter with a 30,000

molecular weight cut-off. The epitope ratio is then calculated by estimation of protein content by standard method and carbohydrate by high-pH anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) method.

D. Example 4: Immunological Studies

It will be appreciated that the inventive glycoconjugates and glycopeptides, as provided herein, are useful for the treatment of cancer and are useful for inducing an antibody response in a subject. Typical protocols for the use of such glycoconjugates and glycopeptides are described in more detail below, and are also detailed in certain references incorporated herein.

1) Immunization of Mice

Groups of mice (CB6F1 female; 6 weeks of age) obtained from Jackson Laboratory, Bar Harbor, ME, are immunized subcutaneously with Polycarbohydrate cluster-KLH (globo H, Le^y, Tn) containing equivalent to 3 μg of total carbohydrate only (the quantity of KLH varied depending on the epitope density) mixed with 10 μg of immunological adjuvant QS-21, a saponin derivative from the bark of the *Quillaja saponaria* Molina tree (Ragupathi *et al. Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 125) (Aquila, Worcester, MA) at 0, 1 and 2 weeks and bled 10 days after the 3rd immunization. The presence of antibody is assayed by an enzyme linked immunosorbent assay (ELISA) as described previously (Ragupathi *et al. Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 125) using the appropriate target antigen (e.g., globo H-ceramide, Le^y ceramide and/or Tn(c)-pamcys as target antigen). The cell surface reactivity can then be tested, for example, the cell surface reactivity of anti- globo H, Le^y, and Tn antibodies are tested on globo H, Le^y, Tn positive cell-lines by flow cytometry assays.

2) Serological Analysis:

ELISA: Enzyme-linked immunosorbent assays (ELISAs) are performed as described (Ragupathi G, Park TK, Zhang S, Kim I-J, Graber L, Adluri S, Lloyd KO, Danishefsky SJ, Livingston PO. Immunization of mice with a fully synthetic globo H antigens results in antibodies against human cancer cells; A combined chemical-

immunological approach to the fashioning of an anticancer vaccine. *Angew. Chem. Int. Ed. Engl.* **1997**, *36*, 125). Serially diluted antiserum is added to wells coated with antigen (0.1 μg) and incubated for 1 h at room temperature. Goat anti-mouse IgM or IgG conjugated with alkaline phosphatase serve as secondary antibodies. Absorbance is measured at 414 nm. The antibody titer is defined as the highest serum dilution showing an absorbance 0.1 or greater above that of normal mouse sera.

3) Flow Cytometry:

Appropriate cells (e.g., cells from the globo H and Le^y-positive breast cancer cell line MCF-7 and Colon cancer cell-line LS-C) are used as target. Single cell suspensions of 2 X 10^5 cells/tube are washed in PBS with 3% fetal calf serum and 0.01 M NaN_3 and incubated with 20 μl of 1:20 diluted antisera or mAb VK-9 for 30 min on ice. After washing the cells twice with 3% FCS in PBS, 20 μl of 1:15 goat anti-mouse IgM or IgG-labeled with fluorescein-isothiocyanate (FITC) is added, mixed and incubated for 30 min. After wash, the positive population and mean fluorescence intensity of stained cells are analyzed by flow cytometry (EPICS-Profile II).